THE UNIVERSITY OF ALBERTA

A QUANTITATIVE GEOLOGIC ANALYSIS OF CRETACEOUS AND JURASSIC OIL AND GAS POOLS IN ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled 'A Quantitative Geologic Analysis of Cretaceous and Jurassic Oil and Gas Pools in Alberta' submitted by Geoffrey James Dickie in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

A computer-based file containing geologic data on most Cretaceous and Jurassic oil and gas pools in Alberta has been built using a modified version of the SAFRAS (Self-Adaptive Flexible-format Retrieval And Storage) system. SAFRAS is a generalized data management system which permits maximum flexibility in file building and data manipulation. For convenience and efficiency, the data are divided into six categories: identification and location, stratigraphic sequence, unconformity relationships, lithology, geometry, and reservoir properties.

A list of 139 data items (exclusive of duplicates) which comprehensively describe the geologic features of an oil or gas occurrence was compiled on the basis of extended use of the file. The proposed file structure is capable of describing the geology of all oil and gas pools in the Western Canada Sedimentary Basin.

Frequency distributions of size measurements (reserves, areas, axial lengths) on oil and gas pools appear to be lognormal when plotted on probability paper, but this cannot be supported by statistical tests. By assuming lognormality, the probability of finding oil or gas pools with specified reserves can be calculated, a value which could be useful in exploration planning.

A population of large pools and one of small pools can be distinguished by the size analysis of Viking oil pools and Wabiskaw gas pools. Factor analysis of the Wabiskaw gas pools produces a composite factor which apparently distinguishes the large Wabiskaw

gas pools, and which, when mapped, defines a zone which is more likely to contain the large pools. The coincidence of a "main" Viking sand development and favourable hydrodynamic conditions characterizes the preferred location of large Viking oil pools.

Simple regression analysis enables the estimation of probable reserves obtainable from a specified area of a reservoir unit on the basis of previously developed pools in the reservoir. Similarly, the probable trend of a newly discovered pool in a well-explored reservoir can be predicted from a weighted trend frequency plot.

The probable western limit of oil occurrence in the Ellerslie Member is identified on pressure-depth plots for Ellerslie oil and gas pools. Correlation of the locations of Ellerslie pools and pre-Mannville erosional features indicates that oil pools are predominantly confined to channels and other negative anomalies on the sub-Cretaceous unconformity surface, whereas gas pools can occur on intervening high areas.

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An integral part of the study was the installation of the SAFRAS system on the IBM 360/67 at the University of Alberta. This was made possible by frequent collaboration with Dr. P. G. Sutterlin, J. dePlancke, and M. Cooper of the University of Western Ontario, the developers of the system. Ann Bartlett-Page was of invaluable assistance in all aspects of the installation and development of the SAFRAS system at the University of Alberta, and her interest has been essential for the successful completion of this project.

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INTRODUCTION

The hydrocarbon phase of the interstitial fluid in a reservoir rock occupies a definable position in space. This position is the result of a number of geological factors which have acted since the sediment was deposited. In this study, the positions of known hydrocarbon accumulations in Cretaceous and Jurassic strata in Alberta have been recorded along with geologic data relevant to that position. Analysis of such data allows general conclusions to be drawn regarding the size and shape of the hydrocarbon accumulations. If the relationships between geologic conditions and hydrocarbon accumulations can also be deduced from this analysis, then exploration for further hydrocarbon reserves can be directed more effectively.

Development of the Study

The project was undertaken in four stages:

1. Definition of the data items to be collected
2. Data collection
3. Implementation of an efficient and flexible storage and retrieval system
4. Statistical analysis of the stored data.

In initial planning, the definition of an oil or gas pool as "...a discrete and continuous accumulation of hydrocarbons..." in a reservoir rock (McCrossan, 1969) was accepted. In practice, the

limits of a hydrocarbon accumulation are difficult to define and are influenced by production and economic factors. The limits of a pool will normally be different for each agency or company which attempts a definition. A suitable practical solution was to accept pool outlines defined by the Geology Department of the Alberta Energy Resources Conservation Board (formerly the Alberta Oil and Gas Conservation Board), which usually result from compromises between exploration company geologists and the geological staff of the Board.

Definition of the data to be collected and the actual data collection began in 1969 following a survey of previous studies of oil and gas pools. Data were collected from maps at the Alberta Energy Resources Conservation Board in Calgary, and from well log files at Imperial Oil Enterprises Limited in Edmonton. The cooperation of both organizations is gratefully acknowledged.

A computer-based filing system was implemented in 1970 in association with the University of Alberta Computing Centre and the data were entered into the file by late 1970. Analysis of the data has been proceeding since that time.

Previous Work

File Systems

Computer-oriented filing systems in the petroleum industry have generally been based on data recorded from individual wells, and experience with such systems in Western Canada has been described by Buller (1964), Stauft (1966) and Fitzgerald and Gagnon (1970).

Several filing systems of this type are available from various service companies.

Files using the oil or gas pool as the basis for data collection have been described by Burk and Ediger (1966), and Brisbin and Ediger (1967). Recommendations from these two documents were used in the design of the oil and gas pools for this study. Burk and Ediger pointed out some potential uses of such a file and these suggestions have also been investigated. During the term of the present project, it was discovered that various organizations were preparing similar files on scales ranging from local to world-wide and exchange of information on file design has been useful.

Statistical Analyses

Many studies have been made on oil and gas pools as discrete entities. Kaufmann (1964) showed a close correlation between the frequency distribution of oil and gas field sizes and the theoretical lognormal distribution function and suggested use of the function as a predictive tool in exploration. Drew and Griffiths (1965) applied concepts of sediment analysis to the sizes and shapes of some oil and gas fields in the United States, considering the hydrocarbon accumulations analogous to sediment grains, and extending the log-normal distribution assumption to the frequency distribution of the plan areas and axial lengths of the fields.

Oil and gas pools in the major reservoirs of the Western Canada Sedimentary Basin were studied by McCrossan (1969) to determine their size frequency distribution, and some of the questions raised by that

study were used as guidelines in the present project. In particular, some groups of stratigraphically related pools seemed to display unimodal lognormal frequency distributions, while other groups appeared to have bimodal lognormal frequency distributions. A bimodal distribution implies that there are two populations of pools, which may have an important bearing on predictions of total probable reserves.

Objectives of the Study

An initial aim of this study was to design a workable computer-based system for storage and retrieval of geologic data related to oil and gas pools. The system had to be capable of accommodating data on the disposition of the pool in space, and also data on the stratigraphic character of the reservoir and associated rocks. The project was seen as a pilot study for a much larger inventory of oil and gas pools on a nationwide scale (Brisbin and Ediger, 1967, Ch. 15) and therefore was designed to accommodate all geologic conditions in which oil and gas pools occur.

As a pilot study, one objective was to experiment with different computer file systems and to recommend one type which could be used in diverse computer installations for the construction of compatible files on fossil fuel deposits. Particular emphasis was placed on the evaluation of a file system designed for geologists by Sutterlin and de Plancke (1969), the SAFRAS (Self Adaptive Flexible-format Retrieval and Storage) system. These objectives are discussed in Part I of this thesis.

For a test of the system and the general concept of deposit oriented data files, collection of simple, readily available data items describing oil and gas pools in Cretaceous and Jurassic reservoirs in Alberta was proposed. It was realized that inclusion of more precise data in the file could provide more detailed control, but the time and cost of collecting such data items would be prohibitive. One of the objectives of the study, therefore, was to analyze and assess the utility of these simple data items and thereby the value of this type of oil and gas pools file. In part II of this thesis the results and implications of the statistical analyses of the data in the file are reported, and geological implications are noted.

PART I

DEVELOPMENT OF A COMPUTER-BASED OIL AND GAS POOLS FILE

CHAPTER 1. STORAGE AND RETRIEVAL SYSTEM

In the initial planning stages of the project, it was known that over 1000 oil and gas pools in rocks of Cretaceous or Jurassic age had been defined by the Conservation Board. To fulfil the objectives of the study, it was recognized that a large amount of data should be collected for each oil and gas pool. The result would be large quantities of data which could only be handled efficiently by a modern, high-speed computer. If the study were to be eventually extended to include all oil and gas pools in Canada, then an efficient data processing system would be absolutely necessary.

Many of the statistical analyses and plotting procedures which have been proposed to evaluate data in the file can only be performed economically by computers and are most efficient if the data are directly accessible to a computer, permitting the required data to be fed directly into the procedures from the data file.

For these very strong reasons, a survey was made of the available computer-based file systems to determine which would best meet the needs of the project.

Card-Based Systems

Most systems designed to store and selectively retrieve geological data have a fixed-format based on the 80-column punch card. This type of system has evolved from the earliest attempts to store and retrieve data by mechanical means where the cards were sorted on the basis of the positions of the punched holes. These card-based systems were limited to the number of data positions on a card unless more than one card for each object was kept and cross-referencing was maintained.

Hutchinson and Roddick (1968) outlined a geologic field data storage and retrieval scheme for a reconnaissance mapping project in the Coast Mountains of British Columbia using the 80-column punch card as the basic input unit. Because of the record size limitation, the system involved much complicated coding both for field observations on outcrops and for laboratory analyses on specimens. For recording of lithologic names, a two-letter alphabetic code was used because of its ease of remembering and interpretation. Other data on veins, faults, inclusions, etc., were represented by one- or two-number codes.

According to Hutchinson and Roddick, the advantages of such a heavily coded system are:

1. The ease of keypunching the data on to cards and of verifying the punched cards,
2. the ability to use the card decks on inexpensive sorting and collating machines for initial processing, and
3. faster data input to a computer and more efficient processing and programming.

The disadvantages presented by such a system for the type of oil and gas pools file planned were:

1. The inflexibility of the data which could be stored on each card,
2. the extensive programming required for each selective retrieval step, and
3. the complex coding necessary to include all the required data on one card.

The card-based system is most suitable for well-defined studies, in which the number and type of data items is fixed and where there is a minimum of coding required, such as geologic field mapping projects. Wynne-Edwards et al. (1970) showed the great advantages that computer processing of field data offered in mapping of the Grenville Province in Quebec. This type of system can be used effectively in recording and processing structural data as described by Haugh et al. (1967).

Fixed-Format Files on Magnetic Tape

In the project reported by Wynne-Edwards et al. (1970), the number of cards generated was too great to be handled efficiently and safely, so the data from the cards were transferred to a fixed-format file on magnetic tape, retaining the card format. Storage on magnetic tape is safer than storing punch cards and also removes the effective single-card limit to the amount of data to be stored for each station. This type of file was used as an interim stage in the development of the oil and gas pools file when only the measurements on the size and shape of the pool had been recorded. These data were punched on

cards and then placed into a fixed-format file structure created in PL/1 language.

In such a fixed-format system, the record is divided into defined fields which are determined by the output statement of the writing program. The record must then be read into any calling program by an input statement having a comparable format so that each data item will be associated with the correct identifier. In a retrieval program, fields within each record are searched under the specified conditions and the selected data is written out or used as input for further calculations. The data stored in the system are identified by their position within each record. Computer systems and programming languages presently in use are designed to operate most efficiently using this type of data transfer.

Punch cards are simply tools for interfacing between the data collector and the computer filing system. The card columns are used as a continuous stream of characters so that any number of cards may constitute one record; in the case of the interim stage of the present study, three cards constituted one record.

Because of the fixed data positions within each record, the input and output statements for a particular format are unique. If a change in the data structure is required - for example, the addition, subtraction or rearrangement of one or more data fields - new input/output control statements are necessary throughout the system. Essentially, a new data format must be programmed and the initial data transferred to the new structure along with the additional data which is read in.

Such a situation did occur in constructing the interim oil and gas pools file when more data on porosity, water saturation, pressures,

and elevations became available for the records already built. The amount of programming involved for this minor change indicated that as the file became more complex, changes would be more difficult and flexibility in the data storage system would be diminished.

Variable Length Record Systems

Probably the most widely used and most extensively developed file systems in geology are those based on data derived from wells drilled in petroleum exploration. A number of commercial systems of this type are presently in use, and numerous systems have been developed by individual exploration companies. A case study of one such system (Stauft, 1966) used by Imperial Oil Limited from 1951-1966, indicated the difficulties encountered in developing a punched-card system which evolved into the largely magnetic tape storage system presently in use by Imperial.

The Imperial Oil Well Data System has the well as its basic unit for data recording and storage. Data from each well are divided into a number of categories, e.g. formation markers, cored intervals, water analyses, etc., which contain groups of associated data items. It was apparent to the writer that this concept of data organization could be applied effectively to an oil and gas pools file, using the individual pool as the basic unit, and different aspects of the geology and geometry as categories. However, when the data were being collected, no variable length record systems were available at reasonable cost, and the development of a new system of comparable type would have been too costly in time and money.

Flexible Format File System

At an early stage in the project, information became available (Sutterlin and de Plancke, 1969) about a data storage and retrieval system which appeared to be ideally suited to the experimental nature of the project. The system was designed to be "data-controlled" "user-oriented" and was adaptable to storage and retrieval of any type of data. The system was investigated primarily for use with the oil and gas pools data but also because of its potential applications in other areas of geology. The designers have called the system the Self-Adaptive Flexible-format Retrieval And Storage (SAFRAS) system and it has been copyrighted by the University of Western Ontario.

SAFRAS System

The SAFRAS system consists of a set of programs, written in COBOL programming language, which builds a file on tape or disk from a list of data specifications supplied by the builder of the file and from the data entered in a "free" format. From the data specifications, the system builds a skeleton library of programs which control the data flow into the file, selective retrieval of data items, and the editing of items in the file. The operations of file construction, retrieval, and editing require no programming by the builder of the file.

There are four points of contact between the user and the system:

a) design of file structure and data specifications,

b) entry of data in "free" format,

c) editing of data items in the constructed file, and

d) retrieval of specific data from the file.

a) File structure and data specifications

Observations are generally made on a specific object or a defined area such as a rock outcrop, a hand specimen of rock, or, in this study an oil or gas pool, and the file is designed to store these observations. This central object or area is called a station in SAFRAS terminology. The data collected for each station are grouped into logically associated sets of data such as location data, stratigraphic sequence data and lithologic data, and these sets are designated as record types. The record, which is the basic structural unit in the SAFRAS system, may occur more than once for each record type, but consists of the same list of data specifications each time. The system can accept up to 99 different record types (i.e., 99 different types of associated data), and there is provision for up to 99 records in each particular record type. There is then a potential for 99^2 (=9801) records for each station, and each record may contain an unlimited number of data items.

The file builder must make a list of the data items likely to be collected at each station, assign a unique data name for each data item, and arrange them into logically associated types. Data names must consist of 30 or fewer alphabetic or numeric characters or the spacing, '-', character. These restrictions are limitations of the COBOL language. The maximum number of characters required by the input data corresponding to each data name must be specified, as well as the type of data (alphabetic, alphanumeric, numeric) to be entered. The file design and definition of data names for the oil and gas pools file is discussed in Chapter 3.

b) Entry of data in "free" format

Using the data specifications, a document for collection of the actual data can be generated by the system. On this source document, alternate lines containing the data items names are printed above blank spaces where the data can be entered (Fig. 1, back pocket). The spaces for data entry are separated by some delimiter (generally a slash, '/', character). The only requirements for the data being entered into the file are that the record number, preceded by an asterisk (e.g. *0101), occur at the beginning of each record, and that all the data items be separated by a specified delimiter.

If a field is blank, the delimiters are punched in successive columns, conserving card space. The keypunch operator merely punches all the characters that appear in alternate line on the source document and the data are read from the cards and placed in position in the file by the skeleton programs. The final file which is stored on magnetic tape or disk actually has a fixed format and each record occupies the maximum possible dimensions as defined in the data specifications. However, if there are no data entered for any particular record, then there is no space allocated in the final "fixed" file for that record. If the data subsequently becomes available, the file can be edited to incorporate the new data.

c) Editing of data items in the constructed file

In the process of file building, some errors in the data will be recognized by the system and warnings will be printed out. Major errors may require that the data cards be corrected and the file

regenerated. Many errors can be eliminated by using the EDITOR program of the system, a much simpler procedure. Commands recognized by the EDITOR program are DISPLAY, ALTER, CREATE, DELETE, followed by the sequence number of the station in the file, the record number, the data name, and (for ALTER only) the new value to be entered for the data item.

d) Retrieval of specific data from the file

Possibly the most attractive feature of the SAFRAS system was the simple yet powerful format of the retrieval request. This request consists of three parts: the conditions statement, the output command, and the output format statement. The conditions statement is optional, and allows the user to apply any number of conditions (none if the statement is omitted), joined by AND or OR to search for the required stations in the file.

Once the required stations have been selected by the conditions statement, any data from those stations can be listed in print, on punched cards, or on tape, by including the data item name in the output command. An option immediately following the PRINT, PUNCH, or WRITE commands allows the length of the output record to be specified.

The format in which the data is printed, punched, or written is then detailed in the format statement. The form of display on a printed page or the arrangement of the retrieved output on cards or tape for input to subsequent programs is controlled through this statement. All symbols used in the format statement are standard COBOL symbols and can be easily learned. A valid retrieval request for the oil and gas pools file is shown in Appendix III.

Evaluation of SAFRAS System

The main advantage presented by the SAFRAS system was its flexibility in the definition of data specifications and in the actual file-building process. The file on oil and gas pools was experimental and the types of data to be stored in the file were by no means well defined. A system where data items could be added or discarded easily was essential. Also the actual data being collected became available at different times and it was necessary to be able to analyze the data in the file at different stages during data collection.

Once the system was converted to function on the IBM 360/67 at the University of Alberta Computing Centre, maintenance of the system was handled by a systems analyst, Miss Ann Bartlett-Page, on a part-time basis. This arrangement helped keep the cost of installation and operation of the system low.

The system is designed only for storage and retrieval of data and contains no facilities for even basic statistical analyses. Desirable features would be an extension of the retrieval request format to allow condition statements more complex than direct comparisons, and the addition of commands to perform summaries and statistical computations.

One feature which has caused a considerable increase in the number of data names specified is that a retrieval search cannot be made within a data field. Examples of how this has affected the oil and gas pools file are discussed in Chapter 3. All of these problems have been or are in the process of being solved either at the University of Alberta, or at the University of Western Ontario, in an effort to develop the SAFRAS system into a more powerful geological

tool. The adaptations made to the original SAFRAS system at the University of Alberta, particularly with respect to retrieval formats, produced, in 1971, the UASAFRAS system, and this system has been used in data evaluation and analysis.

CHAPTER 2. CRETACEOUS AND JURASSIC OIL AND GAS POOLS FILE

Deposit Oriented Files

The practice of organizing files based on discrete occurrences of a valuable commodity (a deposit) is common to companies or agencies involved in the exploitation or regulation of natural resources. The main use of such files has been to control the production of the commodity and to provide an estimate of future potential reserves. For this purpose, the Alberta Energy Resources Conservation Board maintains a reserves and production data file which is based upon defined oil and gas pools to permit monitoring of the progressive depletion of each pool as the oil or gas is produced. The large oil production companies also maintain similar files and exchange data with the Conservation Board.

Very little geological data is stored in these files. In exploration for oil and gas pools, where more geological data is used, the file systems are based on wells drilled in prospective geologic basins. In these systems, there is a considerable amount of geologic data stored, but it is difficult to synthesize the data from scattered wells to apply to each discrete hydrocarbon accumulation.

Recently, Burk and Ediger (1966) and Brisbin and Ediger (1967) have urged that computer-based geological files be set up with the deposit as the basic unit - in this case, the oil or gas pool. The reasons proposed by these authors for setting up separate files on oil and gas and other mineral deposits are that:

1. The widespread accessibility of the data would "...provide the basis for an increased understanding of the geological controls that govern the occurrence of known deposits...";
2. The files would enable more reliable predictions of future potential reserves of the mineral.

The eventual development of a wide range of computer-based files on mineral deposits in Canada is envisaged by these authors. Basic data on the location and geology of the mineral deposits would be common among all the files and would be available to interested workers. This would enable rapid comparisons to be made between the geology of different deposits, and reduce the time necessary for literature searches. Also, the availability of comprehensive files on mineral deposits would allow more complete resource inventories to be made.

Alberta Oil and Gas Pools Data

Geometric, reservoir, and some geologic data on major oil and gas pools in Alberta have been published by the Alberta Society of Petroleum Geologists (White, 1960; Century, 1966; Larson, 1969). Annual reports are published by the Alberta Energy Resources Conservation Board giving reservoir and production data on the oil and gas pools in the province, and the Geology Department of the Board keeps current isopach maps of most pools. These maps are not publicly available but were released for this study.

A significant aspect of the present project was the devising of ways for recording the available geological data in a computer processible format, while retaining as much of the "sense" of the

deposit as possible. Subsequently the recording format was to be evaluated and a set of standards recommended as a basis for future files containing geologic data on oil and gas pools. This objective is consistent with that of the Ad Hoc Committee on Storage and Retrieval of Geological Data in Canada (Brisbin and Ediger, 1967).

Geological Measurements on Oil and Gas Pools

Measurements that can be made on oil and gas pools fall into two broad categories - geological and engineering, with a small degree of overlap between them. Geological measurements may be considered to be either stratigraphic (including stratigraphic sequence, lithology, and depositional environments), or structural (shape, size elevation, and presence of geologic structures). Certain reservoir and reservoir fluid parameters including pressure, water saturation, salinity, oil gravity, are also important in considering the geology of a deposit. Such properties have frequently been used in classifying oil and gas fields on the basis of their contained fluids, or attempting to determine the origin of the hydrocarbons.

Geological measurements made on any deposit may be either (a) descriptive, or (b) quantitative.

(a) Descriptive measurements have no definable frequency distribution and belong to an "open" system of measurement where no meaningful limits can be placed on their variation. Such properties conform to either the nominal or ordinal scales of Krumbein and Graybill (1965), and lend themselves only to elementary statistical analysis.

As an example, the colour of the reservoir rock is not easily quantified and is generally recorded as one of a number of classes of

colour. The relative percentages of reservoir rocks which fall into the different classes may be a useful statistic but the "mean colour" has very little significance. However, the colour of the reservoir rock may be useful in combination with other properties in indicating changes in the nature of the reservoir rock over an area.

It is therefore important that descriptive measurements be stored in readable and consistent forms so that they can be used as a basis for retrieval from the file and that when retrieved they can be easily recognized and understood. It has been found that a convenient form for recording and storing descriptive data is the four letter mnemonic code generated from its full name using the procedure suggested by Cohee (1967). The four character code is the most efficient for computer processing.

(b) Many of the quantitative measurements made on oil and gas pools are also "open ended" (interval scale of Krumbein and Graybill) and apparently cannot be defined by any particular distribution function. Included in this group are the preferred azimuth (trend) of the pool, the location of the pool, porosity of the reservoir rock, and others. Since it is difficult to define the distribution function of these variables, statistics such as mean and standard deviation have only limited significance and the variables must be treated carefully in such techniques as factor analysis. If the relative frequency distributions are known in detail, then the bias introduced can be accounted for.

Other quantitative measurements (those conforming to the ratio scale of Krumbein and Graybill) do approximate defined distribution functions but few of these are statistically confirmed by detailed

studies. The one measure which has been studied in most detail is the size of the pool, and the various ways of measuring it (McCrossan, 1969; Drew and Griffiths, 1964; Kaufmann, 1964). The conclusion generally derived from these studies is that different measures of size tend to be lognormally distributed. This conclusion is arrived at partly by analogy with other natural phenomena which follow the lognormal distribution and partly from graphical analysis of measurements.

Data Organization in Oil and Gas Pools File

The locations at which data have been collected and recorded for the file are the individual oil and gas pools, the "stations" in SAFRAS terminology (Sutterlin and de Plancke, 1969). The data items describing such an oil or gas pool fall into three logical groups:

1. The identification and location of the pool,
2. the size and shape of the fluid accumulations and the properties of the fluid, and
3. the geology of the reservoir and associated rocks.

The realities of assembling the many data items for each pool require that these divisions be further subdivided. Other priorities to be considered in grouping the data items are:

a) association in the data collection process

b) association in useage.

Subdivision into Record Types

Location, Size, Shape

Measurements of pool geometry (areas, trends, thicknesses), as

well as structural trends, were recorded together from geological maps of the Alberta Energy Resources Conservation Board, but reservoir parameters and fluid properties were derived from other sources and were recorded separately. Therefore, one record type was set up to contain the geometric measurements and structural data (record type 5) and another to contain the reservoir parameters and fluid properties (record type 6). Certain of the data items in record type 6 were located in summary publications (White, 1960; Century, 1967; Larson, 1969) which also contained technical data on the number of producing wells and well spacing. These technical data were included in record type 6 for convenience.

It was considered essential to retain the identification and location of the pool as a complete entity in record type 1 because a proper definition of the pool was needed at the beginning of the station data. However, these records were assembled after making many of the measurements on the pools and also after much of the stratigraphic and unconformity data had been compiled. Consequently, they had to be assembled from at least four data sources, a time-consuming process. Also, the SAFRAS system requires that a type 1 record be present for each pool, therefore no actual file building on the computer could begin until the type 1 records had been coded - i.e. until most of the data had been collected for each pool.

For SAFRAS-style system files, it is recommended that type 1 records be composed of data items readily available at the start of file-building.

Geology

Data on the geology of the reservoir were collected mainly from two sources - publications and lithologic well logs. The name of the reservoir unit is known from the definition of the pool, and therefore the stratigraphic sequence can be found in major stratigraphic summaries such as the Geological History of Western Canada (McCrossan and Glaister, 1964). The lithologic logs prepared by Canadian Stratigraphic Services Ltd., and made available for this study by Imperial Oil Limited, Edmonton, were used to record the detailed lithology of the reservoir rock and the overlying and underlying sections. Because of this split in data access and also because of the differing definitions of lithologic and stratigraphic units, record type 2 was set up to contain the stratigraphic sequence data, and record type 4 for the lithologic data.

The relationship of a pool to unconformities was considered important from the aspect of migration and accumulation of hydrocarbons. To maintain consistency in measurements about the stratigraphy at the unconformity, it was found necessary to refer to both the lithologic logs and to publications. Therefore, a separate record type (type 3) was defined to contain the unconformity data.

In summary, the data categories decided upon for the file were:

1. Identification and Location
2. Stratigraphic Sequence
3. Unconformity Data
4. Lithological Data
5. Geometry
6. Reservoir and Production Data

Details of Data Collected for each Pool

A complete list of the original data specifications for each pool is given in Appendix I. Important and contentious features of the data collected can be discussed by record type.

Type 1 Identification and Location

The type 1 record is critical to the file system in that it identifies and locates the station, in this case, the pool, for which the data are recorded. The record is designed to contain often-used data in an accessible format and will probably be the record type referred to most often. Many of the data items were suggested by Brisbin and Ediger (1967). In Alberta the definition and identification of fields and pools by code number is done by the Energy Resources Conservation Board and the official pool designations of that body were followed as closely as possible. Data also included in the type 1 record refer to the type of hydrocarbons in the pool (oil or gas, or both), the regional tectonic setting, and published references to the pool.

Difficulties were encountered in determining the best way to record the locations of pools. Ideally, the entire, three-dimensional pool outlines could be digitized and used as pool locations. However, a simpler and less time-consuming method of location was used (with consequent loss of detail). Major and minor axes were defined for each pool (see type 5 - Geometric Data) and one location was taken at the well drilled nearest the intersection of these axes (Fig. 2). The use of well site locations gives each pool an actual reference source - the suite of well logs against which data in the file can be

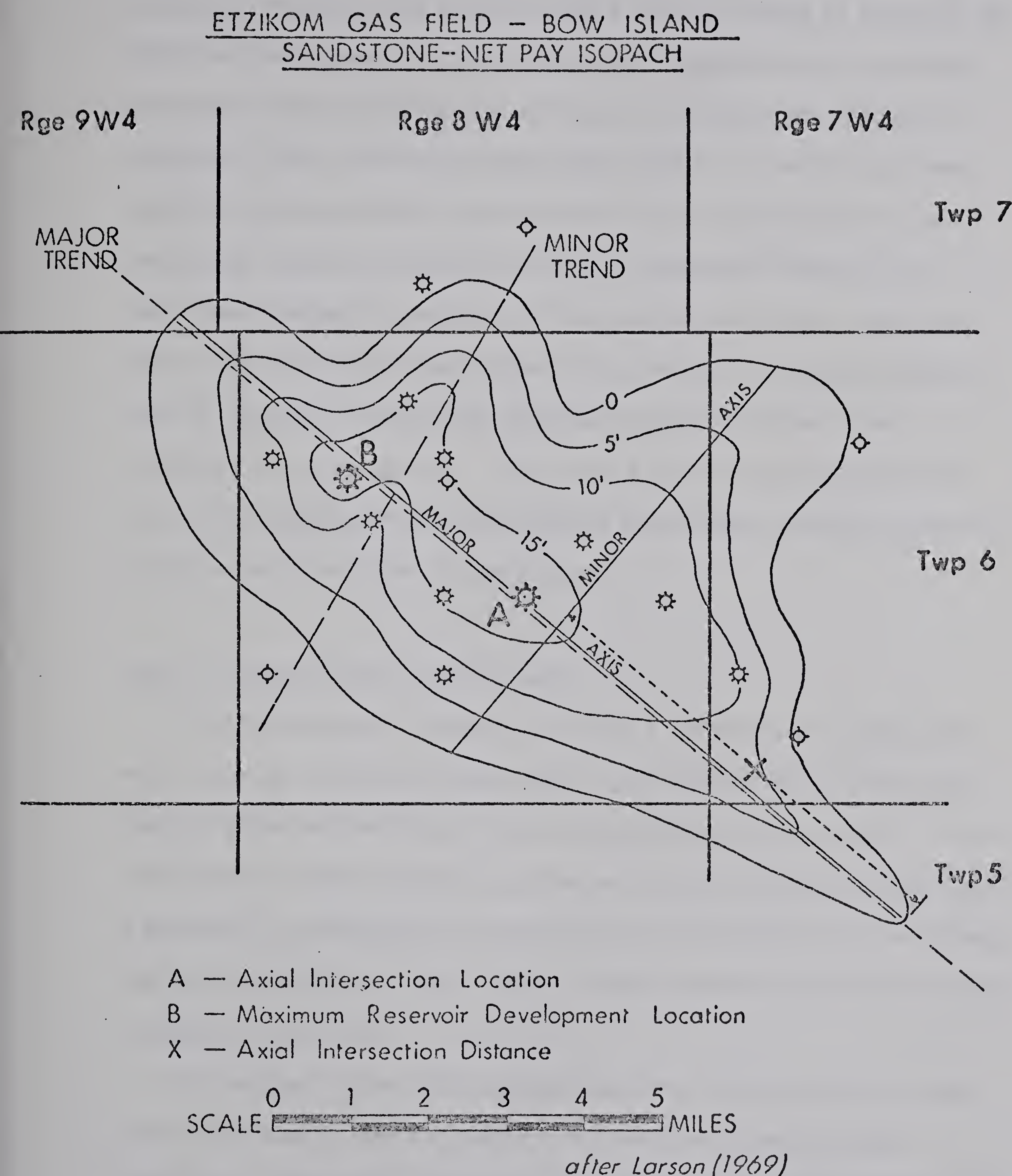


Figure 2.-Size and shape measurements on oil and gas pools.

checked. Provision was made to record locations both in terms of the Dominion Land Survey which is used by oil companies and the Energy Resources Conservation Board, and also in latitude and longitude, which is a more universally applicable system. It would have been useful to have recorded locations also in the coordinates of some projection system (preferably Universal Transverse Mercator) to facilitate automatic plotting of data points, but those coordinates can easily be derived from either of the others. A second location, that of the well in which the maximum reservoir thickness was recorded, was also entered. This second location perhaps could be useful in studying the stratigraphy of particular reservoirs and its relation to hydrocarbon accumulations.

Type 2 Stratigraphic Sequence Data

The stratigraphic sequence in which a hydrocarbon accumulation occurs can be defined by three units - the reservoir unit, the unit overlying the reservoir, and the unit underlying the reservoir. The definition of units laterally equivalent to the reservoir is basically a problem in stratigraphic terminology and correlation, and no attempt was made to solve it in this study. Hence lateral equivalents are not included in the file.

The design of the file system allows for the creation of three records of type 2, one for each of the units referred to above (reservoir, underlying, overlying). One composite record for all data on the stratigraphic sequence would have been too long for convenient coding and for efficient manipulation of the file.

In order that searches of the file could be made at a number of levels of definition of rock stratigraphic units and because of the inability of the SAFRAS system to search within a data field, separate fields were defined for group, formation, member, and informal names, modifiers, and ages, for each stratigraphic unit discussed. Codes were developed using the system suggested by Cohee (1967): a four-letter mnemonic code for the name of the unit, a one-digit code referring to a modifier of the unit (U-upper, M-middle L-lower), and a three-digit hierarchical code for the geologic age of the unit.

The inferred depositional environment of each unit was recorded as two items - general and detailed - to allow more flexibility. A two-digit code represented the general environment (see Table I) and space for a twenty-character alphanumeric string was reserved for detailed comment.

Type 3 Unconformity Data

A relationship between significant hydrocarbon occurrences and regional unconformities has been observed in most petroleum provinces. The actual effect of the unconformity on the generation and accumulation of oil and gas is not well understood but at least it is frequently the locus of porous aquifers through which basin fluids can migrate and within which they may be trapped. Because of this lack of definite knowledge, it was decided to record empirically whether the pool was related to an unconformity, the spatial relationship, and the stratigraphy across the unconformity.

TABLE I

CODES FOR GENERAL DEPOSITIONAL ENVIRONMENT

10 continental	20 intermediate	30 marine
11 alluvial fan	21 coastal plain	31 littoral
12 alluvial plain	22 lagoonal	32 near shore
13 lacustrine	23 deltaic	33 stable shelf
		34 shelf edge
		35 basin edge
		36 basin centre

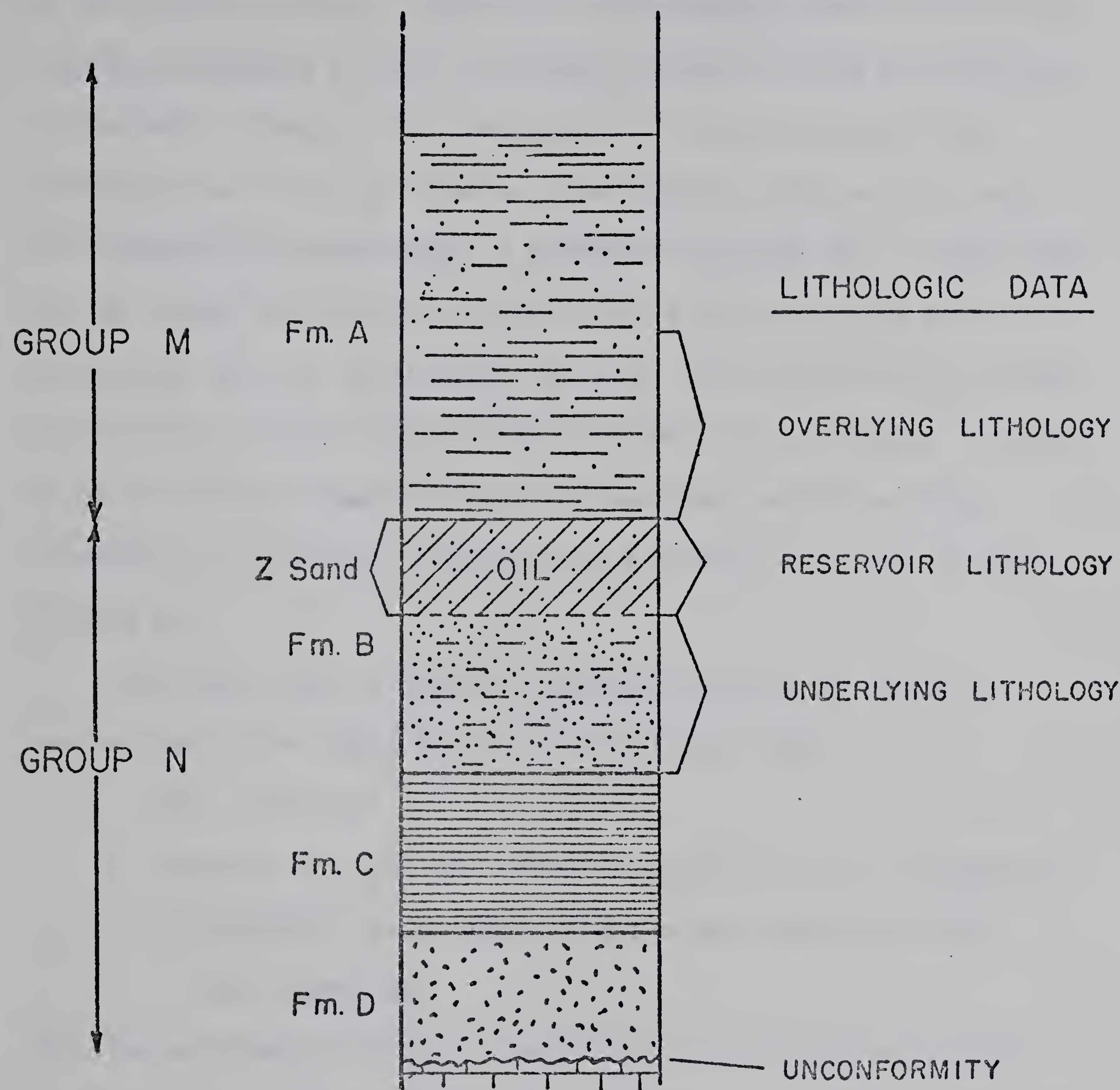
The basic problem encountered was establishing a consistent standard for deciding whether a pool was related to an unconformity. At the risk of not recognizing some subtle connections between the unconformity and the pool, it was decided that a pool was "related" to the unconformity if the overlying, reservoir, or underlying lithology (as defined for record type 4, p. 29) was in contact with an unconformity (see Fig. 3). In practice, this meant that pools which were more than approximately 100 feet vertically from an unconformity were considered unrelated to it.

The system for recording the stratigraphic units adjacent to an unconformity was identical to that used for the type 2 records.

Type 4 Lithologic Data

The relationship between lithology and hydrocarbon occurrence is an important but indirect one in that the presence of particular lithologies does not necessarily indicate the presence or absence of oil or gas. However, certain lithologic characteristics such as clast composition, grain size, and sorting, are often good indicators of the ability of rocks to act as reservoirs or seals for an oil or gas pool. The purposes of a regional file on oil and gas pools would seem to be best achieved by recording lithologies of the reservoir rock and of the underlying and overlying rock units. If there is a rapid lateral facies change within the reservoir unit, the lithology laterally equivalent to the reservoir rock should also be recorded, but this was not possible because of limitations in availability of data.

DIAGRAMMATIC COLUMNAR SECTION



STRATIGRAPHIC DATA

OVERLYING GROUP : Group M
OVERLYING FORMATION : Formation A

RESERVOIR GROUP : Group N
RESERVOIR FORMATION : Formation B
RESERVOIR INFORMAL : Z Sand

UNDERLYING GROUP : Group N
UNDERLYING FORMATION : Formation C

UNCONFORMITY

Pool is not related to unconformity

(Reservoir in Formation D would be related.)

FIGURE 3

Within the limits of an oil or gas pool, there are generally two or more wells, and the lithologies of the desired units for the pool should be averages of the lithologies recorded in each well drilled in the pool. However, the limitations of the data source (the lithologic well file of Canadian Stratigraphic Services) are such that generally only one well is available for each pool. Often there are no logged wells within the pool limits and the logged well which is nearest the pool outline must be used. The difficulties involved in locating suitable logged wells, from which the lithology laterally equivalent to the reservoir could be recorded, would have been formidable, and the data obtained would probably have been of only limited use.

The method used to record lithologic data was to locate the nearest available logged well to the pool, and note

1. the location,
2. whether the well was inside or outside the pool boundaries,
3. if outside, the distance from the well location to the pool boundary.

Once the well was defined, the reservoir unit was located on the lithologic log and the lithologies over an approximate 100 feet interval above and below the reservoir rock were taken as the overlying and underlying units respectively (Fig. 3).

Discrete lithologies (e.g. sandstone, shale, etc.) were used as the basis for each record and provision was made to describe three discrete lithologies and their relative proportions from each of the overlying, reservoir, and underlying units. There are, then, nine possible type 4 records for each pool. However, the full nine

lithologies are rarely recorded and usually between three and six records were sufficient to describe the lithology related to the pool.

Stratigraphic Designation: Within each record, the first three data items identify the proportion of the particular rock type within the unit and the relation of the unit to the hydrocarbon accumulation (i.e. whether overlying, reservoir, or underlying). These three data items define the particular lithology thereafter described with respect to the oil or gas accumulation. The formal stratigraphic nomenclature is similar to that used in type 2 records except that the three fields (unit name, modifier, and age) are combined into one since these designations will probably not be the primary condition in a retrieval search.

Lithology Description: Standard terms are used to describe the details of the lithology (e.g. colour, grain size, mineral composition, cement, matrix) and these are recorded where possible in four letter mnemonics (Table II). These terms were designed to extract most of the data contained on recent lithologs published by Canadian Stratigraphic Service Ltd. However, many of the logs used were produced some time ago and are of poorer quality, so the descriptive lithologic data are far from complete.

TABLE II

ABBREVIATION SCHEMES FOR LITHOLOGIC DATA COLLECTION

Data Item	Examples of Data		Abbreviations
CRYSTALLINITY	Crystalline		CRSL
	Granular		GRLR
(GRAIN) SIZE	4 mm	Pebble	PBBL
	2-4 mm	Granule	GRNL
	1-2 mm	Very Coarse Sand	VCSD
	0.5-1 mm	Coarse Sand	CRSD
	0.25-0.5 mm	Medium Sand	MDSD
	0.125-0.25 mm	Fine Sand	FNSD
	0.0625-0.125 mm	Very Fine Sand	VFSD
	0.032-0.0625 mm	Coarse Silt	CRSL
	0.004-0.032 mm	Medium-Fine Silt	MFSL
	0.004 mm	Clay	CLAY
CLAST-COMPOSITION	Quartz		QRTZ
	Feldspar		FLDP
	Dolomite		DLMT
ACCESSORY-MINERALS	Chert		CHRT
	Glauconite		GLCN
FOSSIL-TYPE	Plant fragments		PLNT
	Fish scales		FSSC
	Ostracods		ORCD
SORTING	very good		VRGD
	good		GOOD
	moderate		MDRT
	fair		FAIR
	poor		POOR
ROUNDING	rounded		RNDD
	angular		AGLR
POROSITY TYPE	intergranular		IRGL
	intercrystalline		IRCL
	fracture		FRCR
	pinpoint		PNPN
	vuggy		VGGY
	intraskeletal		IRLL

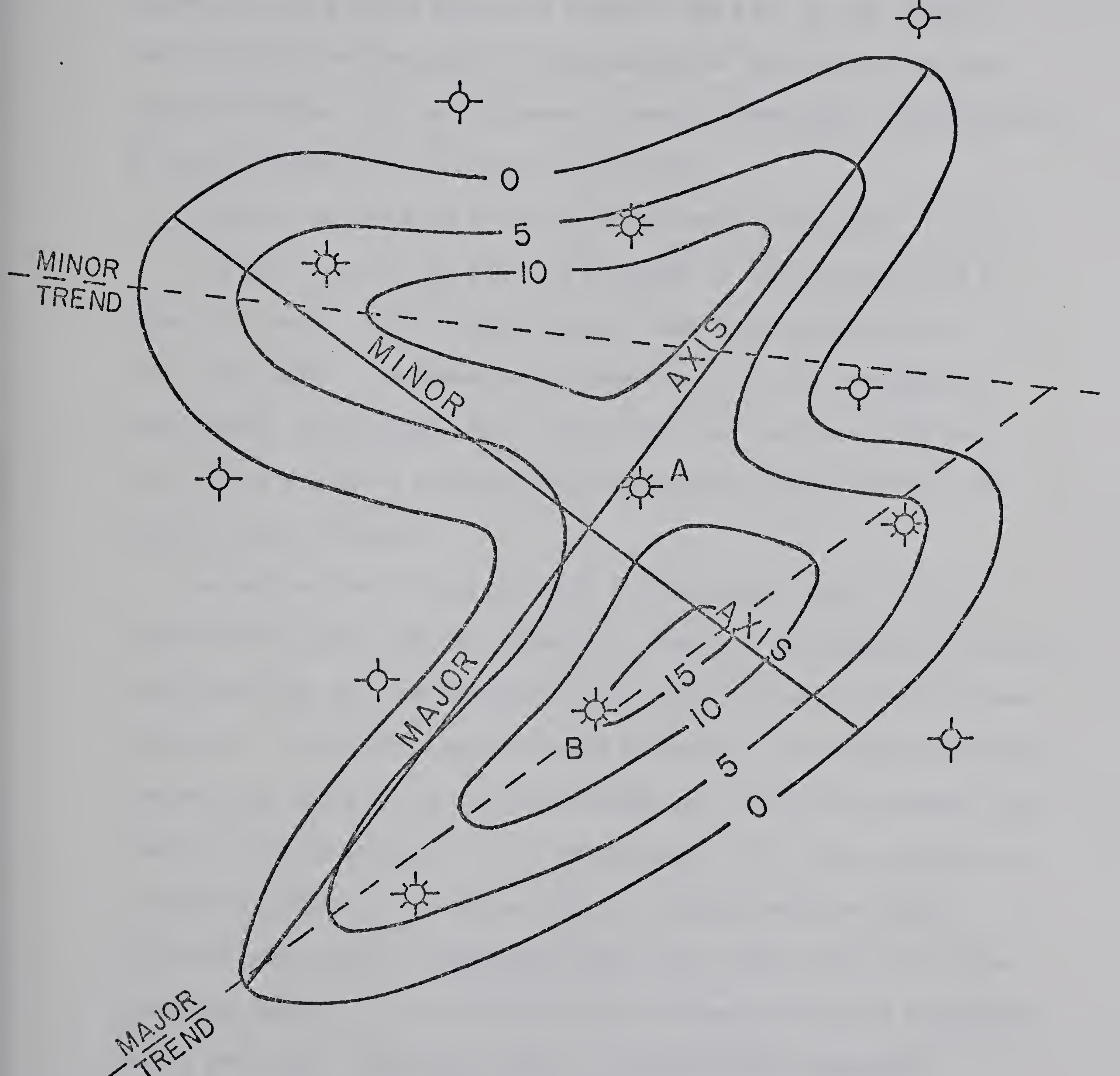
Type 5 Geometric Data

Because an oil or gas pool occupies three-dimensions in space, a method had to be designed which would characterize the size and shape of the pool with respect to all three axes. The pool outlines were taken from isopach maps prepared by the Geology Department of the Energy Resources Conservation Board. These outlines are projections of the margins of the pool on to a horizontal surface (see Fig. 4), simplified in that the shapes of the upper and lower surfaces of the pool are not individually recorded. These outlines, the average thickness, and the depth to the top of the pool, would give a reasonably accurate representation of the shape of the pool in three dimensions. The time required to code the outlines digitally would be prohibitive for a study involving any large number of pools. For a detailed study of pools in a particular region, digital representation of the contours may be required but for a regional study such as this, a less time-consuming method had to be devised.

Size and Shape: Drew and Griffiths (1965) applied the measurements used in studies of sedimentary particle shapes to oilfields in the U.S.A., considering each oil accumulation analogous to a single particle. Their approach was followed and modified for this study (see Fig. 4).

Using the isopach projection of the pool, a major axis was defined as being the longest straight line that could be drawn within the pool outline. The length and azimuth of this line were measured. A minor axis was constructed as the longest straight line in the pool that could be drawn perpendicular to the major axis and its length

DIAGRAMMATIC GAS POOL ISOPACH



A – AXIAL INTERSECTION LOCATION

B – MAXIMUM RESERVOIR DEVELOPMENT LOCATION

FIGURE 4

was recorded. Also the shape of the cross section along each axis (anticlinal, synclinal, undulating, etc.) was recorded by visually estimating the profile along the trace of the axis on the isopach. The distance from the point of intersection of the axes to the east end of the major axis was recorded to enable approximate reconstruction of the pool shape from the data in the file.

Examples of the size and shape measurements are shown in Fig. 4.

The plan area of the pool was measured by overlaying a grid of known unit areas on the isopach map and counting the grid units within the pool. The Conservation Board has official planimetered measurements of each pool area, and if the pool outline as defined publicly by the Board coincided with the geologic pool outline, the official area was used.

Two values for oil and gas zone thickness were used to try to improve the accuracy of the parameter. Obviously, thickness varies over the entire pool but one definite value is the maximum oil or gas zone thickness. In determining an average thickness, the method used by the Conservation Board is to calculate volume and area with planimeter and find the average thickness from (volume/area). For this project, the average thickness was estimated from the isopach maps and these estimates were checked frequently against the values obtained by the planimeter method. The deviation of the estimates from the calculated values was small, indicating that the procedure was acceptable.

The calculation of the position of the pool in the third or vertical dimension was recorded from the electric logs of the wells drilled in the pool as the elevation with respect to sea level of the top of the reservoir interval at the axial intersection location.

Measurements of pool geometry are shown on Fig. 4 and summarized in Table III.

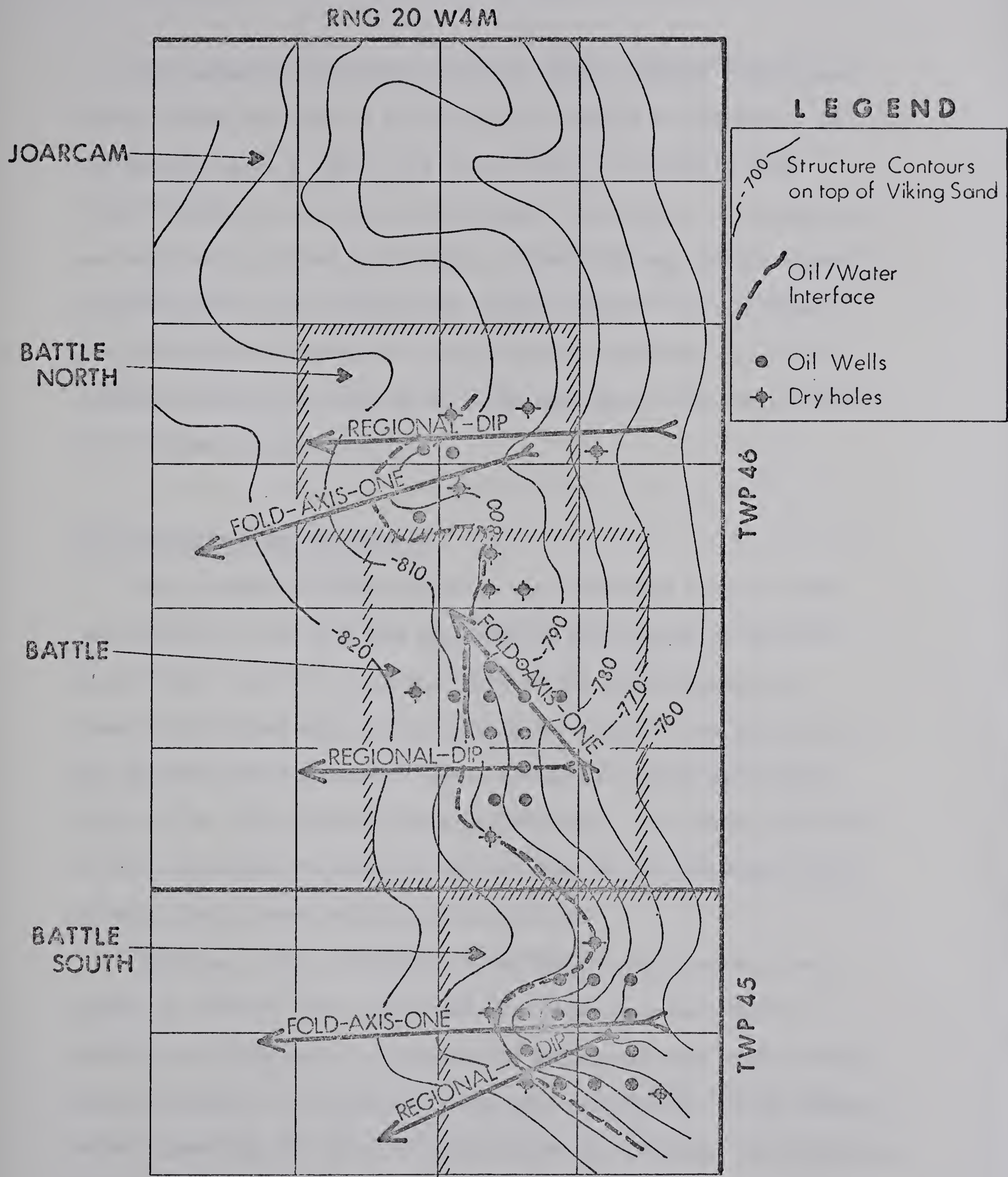
<u>Structure</u>: Three structural elements, regional dip, folding, and faulting, were considered to have possible significance in the formation of an oil or gas pool. Such elements are best recognized in the subsurface on structural contour maps constructed on horizons adjacent to the reservoir rock. Regional dip measurements and fault directions are usually obvious on these maps but, particularly in the plains portion of the Western Canadian Sedimentary Basin, there are very few well-defined structural closures. Folds generally show up as "noses" on structural contours and the measurements of fold orientations were made on the basis of these minor anomalies on the contour maps (Fig. 5). In the data specifications, provision was made for recording two such orientations, because the interaction of folding is often responsible for accumulations.

Type 6 Technical Data

The data recorded for each pool in type 6 records are those parameters of the reservoir rock and of the contained fluids that reflect directly on the geology and hydrodynamics of the pool. The most widely-used figures are the in-place reserves of oil and gas for each pool, although porosity, water saturation, oil gravity, and initial pressure are also important. Most of these data were taken from Conservation Board files to maintain consistency.

TABLE III

POOL FEATURE	DATA MEASUREMENT
GEOMETRY	
AXES	MAJOR AXIS - longest straight line drawn in the pool outline (length and azimuth recorded)
	MINOR AXIS - longest straight line drawn in the pool outline perpendicular to the major axis (length recorded)
TRENDS	MAJOR TREND - predominant direction of elongation of pool outline
	MINOR TREND - secondary direction of elongation
AREA	POOL PLAN AREA - planimetered or estimated plan area
THICKNESS	MAXIMUM RESERVOIR ZONE THICKNESS (if available)
	MAXIMUM AND AVERAGE OIL AND GAS ZONE THICKNESSES
LOCATION	
	AXIAL INTERSECTION LOCATION - location of well site nearest the intersection of major and minor axes
	MAXIMUM RESERVOIR LOCATION - location of well site nearest the maximum hydrocarbon thickness
ELEVATION	PAY ZONE TOP ELEVATION - elevation w.r.t. sea level of the top of hydrocarbon zone at the axial intersection location



STRUCTURAL MEASUREMENTS OF BATTLE OIL FIELD

(modified after White, 1960)

FIGURE 5

The summary publications of White (1960), Century (1966), and Larsen (1969) designate a trap type for each oil or gas pool. To include the sense of this item in the file, a very basic trap classification was set up (stratigraphic, structural, or combination) and each pool assigned to one type. Other data such as the number of producing wells, well spacing and "other products" are included in the publications referred to, and these were recorded, not for any immediate purpose, but because of their easy access and their possible use in summaries and displays.

Data Collection and Management

The sequence of data collection was controlled largely by the availability of the data and the physical association of types of data items. Initially, the pool maps of the Energy Resources Conservation Board were made available for study by the author and the detailed map measurements were carried out during July-August, 1969, at the office of the Conservation Board. This phase resulted in the collection of geometric data on most of the Cretaceous pools in which two or more wells have been drilled.

Subsequent data collection at the Conservation Board by the author in February 1970, was aimed at recording as much data as possible on those pools not covered by geological maps (mostly small, one-well pools). The data for these were recorded on "strike-sheets", brief reports by the Board on minor oil or gas strikes. Later analysis of the total file revealed that while axial measurements were available for only 60% of the pools, the reserves in those pools

accounted for 86% of the oil reserves and 87% of the gas reserves in the province. A total of 300 hours was spent by the author recording the geometric data, 225 hours on the pool maps and 75 hours on the strike sheets.

Concurrently with the study on the Conservation Board pool maps, lithologic data were being extracted from logs produced by Canadian Stratigraphic Services and made available by Imperial Oil Limited in Edmonton. These data were obtained by a technician with a little geological training and were recorded in a format designed for direct entry of the data into the UASAFRAS (University of Alberta version of SAFRAS) system file. Acquisition of the lithologic data required six months work.

Later, it was found necessary to rearrange the format in which the lithologic data were to be stored in the computer file. To convert the data into the new format and to add some new data items to the lithology record required a considerable amount of work by an assistant with some geological training. In retrospect, knowing the present capabilities of the UASAFRAS system, it would have been more efficient to have created the file with the initial data and then manipulated the items within the file system.

Literature Searches

The collection of stratigraphic and unconformity data on the Cretaceous pools was essentially a literature search through such comprehensive works as:

Geological History of Western Canada (McCrossan and Glaister, 1964)

Lexicon of Geologic Names in the Western Canada Sedimentary Basin and Arctic Archipelago (Alberta Society of Petroleum Geologists, 1960)

Oil Fields of Alberta (White, 1960)

Oil Fields of Alberta Supplement (Century, 1966)

Gas Fields of Alberta (Larson, 1969)

This search was carried out in May-June, 1970, by a geological assistant and required a minimum knowledge of geological terminology.

Data for record types 1 and 6 were accumulated simultaneously over a three month interval (Oct.-Dec., 1970) from a number of reference sources by an assistant with no geological training because a minimum of interpretation was required. It was realized late in the data collection stage that all the type 1 records had to be coded before any actual file building could take place using the UASAFRAS system. Coding the type 1 records late in the data collection phase was an error in the sequence of the operation and caused the construction of the file to be delayed by some months.

A summary of data collection timing and costs is presented in Table IV.

Keypunching

As the data for the different record types were coded, they were punched on IBM cards and stored temporarily on magnetic tape. When all the data had been stored for all pools, the record types were sorted and card images were arranged according to the serial number of the pool for which the data were recorded. From this series of card

images the UASAFRAS format file was built on another magnetic tape.

Keypunching the coded data required approximately 200 hours.

Systems Control

The establishment of the SAFRAS system on the IBM 360/67 computer at the University of Alberta Computing Services Department required the services of a part-time systems analyst, Miss Ann Bartlett-Page, over a 12 month period. Subsequent development and extension of the UASAFRAS system in PL/1 programming language, and time-sharing mode, has been undertaken by Miss Bartlett-Page as a M.Sc. thesis project.

TABLE IV

SUMMARY OF DATA COLLECTION COSTS

Data Type	Training of Collector	Period	Time	Cost
Geometric and Location (types 1 and 5)	Geological	July-August 1969	200 hours	$500
Lithologic (type 4)	Some Geological	July-December 1969	6 months	$2000
Location and Technical (types 1 and 6)	Geological	February 1970	75 hours	$200
Stratigraphic and Unconformity (types 2 and 3)	Some Geological	May-June 1970	300 hours	$800
Preparation of Lithologic	Some Geological	July-October 1970	300 hours	$800
Identification, Location, and Technical	Non-Geological	October-December 1970	450 hours	$1200
			TOTAL	$5500

CHAPTER 3. EVALUATION OF FILE DESIGN AND DATA COLLECTION

A previous attempt to build a geologic data file on petroleum accumulations in Western Canada was reported on by Burk and Ediger (1966), and the success of the present project can be gauged by a comparison with that file. Burk and Ediger compiled data on non-associated gas pools and showed diagrammatically the availability of the basic data items recommended by the Committee on Storage and Retrieval of Geological Data (an ad hoc committee of the National Advisory Committee on Research in the Geological Sciences). Data on "pool geology" was not readily available from Provincial Government sources and from publications, and it was suggested that further attempts be made to collect and evaluate geologic data on oil and gas pools.

The completeness of data collection for the CRETaceous and Jurassic PETroleum pools (CRETPET) file can be seen in Appendix I, where the amount of data in the file for each data field is recorded. File design can be evaluated in terms of the ease of data collection and the efficiency of the file building process in the UASAFRAS system, and these features are discussed below.

Record Types

The establishment of six groups of associated data items (record types) has proved generally successful both for data collection and management. Two record types (type 3 - unconformity data, and type 4 - lithologic data) were most in dispute because of the possibly unnecessary added storage required.

In the case of unconformity data, the use of a single record to

contain all the data items relevant to the stratigraphy across the unconformity proved to be the most effective storage and retrieval arrangement. Of the 1101 pools in the file, 251 have an unconformity data (type 3) record, obviously a necessary set of data items.

The system for recording lithologic data (type 4) proved too cumbersome for the amount of detail available. The maximum number of lithologies recorded for any pool was 6, and there were only 510 type 4 records representing the lithologies of 148 pools, an average of 3-4 records per pool. This is not a satisfactory return for the amount of time and money spent on collecting and entering the lithologic data (Table 3).

Two planning mistakes were made. Making allowance for nine different lithologies per pool in the file design created pressure to fill in as much lithology data as possible. A considerable amount of data was then accumulated on the original format sheets by transcription from Canadian Stratigraphic Service lithologs. Too much detailed data were acquired at that stage to be handled effectively. The second mistake was changing the input format for the lithologic data record. The original data sheets had to be reinterpreted and coded into the new format, effectively repeating the initial data collection. The redesigned format was clearer and more compatible with the rest of the file, but it is doubtful that the improvement was worth the work of the manual changeover. Experience with the UASAFRAS system has shown that the data could have been entered in the old format and later changed internally.

When it became apparent that large amounts of time would be needed to acquire and code the lithologic data, it was decided to enter

lithologic data from the largest oil and gas pools first. Therefore the 148 pools in the file for which there are lithologic records are the largest in terms of reserves.

Recommendations resulting from this experience in acquiring and entering lithologic data into the file are:

(a) reduce the number of possible lithologies for each pool to six;

(b) reduce the number of data items in each record by 33% to 50%;

(c) examine the reservoir lithology of the largest pools first; and

(d) record the underlying and overlying lithologies, only if available at the same source as the reservoir lithology.

Proposed Standard Data Specifications

Through experience in the collection and use of the geologic data, a modified set of data specifications can be suggested for future file design. The major changes recommended are to the type 1 (identification and location) record and the type 4 (lithology) records, and the revised versions of these record types are listed in Appendix II.

Type 1 Record

The first change would be to include the Universal Transverse Mercator coordinates, easting and northing, and the U.T.M. zone number for each pool. The display of data from the file on an X-Y plotter requires rectangular coordinates for each point, and conversion

of other coordinates for each plot is repetitious. The coordinates could be calculated initially from D.L.S. locations (along with latitude and longitude) and then re-entered into the file system by means of EDITOR.

The inclusion of a second location (maximum reservoir development location) in the file has not been justified by the amount of use in subsequent analysis of the data. Also, the definition of the location of the maximum reservoir development as distinct from the maximum pay thickness can be difficult because many pool maps are constructed solely on the basis of pay thicknesses. For stratigraphic comparisons, the true maximum reservoir zone location might be useful, but if its definition is doubtful, then its value is reduced.

As an indicator of pool centre location, the axial intersection location is considered more reliable and is retained.

Type 4 Record

As was suggested previously (p. 47) the maximum number of lithologies for each pool should be reduced to six (*0406) allowing for two lithologies for each of the overlying, reservoir, and underlying units. Similarly, many of the data items in the original specifications have been eliminated because the detail allowed for is not readily available in published form. The low collection rate for such items as accessory minerals, fossils, matrix and cement, and permeability prompted their removal. The geographic location of the source of the lithologic data is not a likely parameter on which a search would be conducted, and therefore can be recorded more

efficiently as one data field.

These alterations have reduced the size of the type 4 record by 33% (p. 47).

Other Record Types

The design of record types 2, 3, 5, and 6 seems satisfactory for the nature of data collected and analyzed to this time. Also the individual data items appear to be desirable and effective categories for the storage and retrieval of these types of data on oil and gas pools.

PART II

APPLICATIONS OF THE CRETPET FILE

CHAPTER 1. INTRODUCTION

Analysis of Geologic Data on Oil and Gas Pools

The large amount and varied nature of the data assembled on Cretaceous and Jurassic oil and gas pools in the CRETPET file require that the data be selectively summarized so that valid geological comparisons can be made. For this, either analytical or empirical methods may be used.

The analytical approach involves investigating the data itself by examining the frequency distributions of important parameters and attempting to explain these distributions with reference to the geological framework. The interrelationships between parameters can be determined by regression or factor analyses producing composite measures (factors) which may be more sensitive as indicators of geologic conditions favourable for oil or gas accumulation. Most of the results presented in this study were obtained using this approach.

In an empirical approach, aspects of the geology of the area under study are recorded (e.g. on stratigraphic or structural maps), and known oil and gas occurrences are compared with the geology. Geologic conditions which appear to be favourable for petroleum accumulation can be deduced visually, and these relationships used

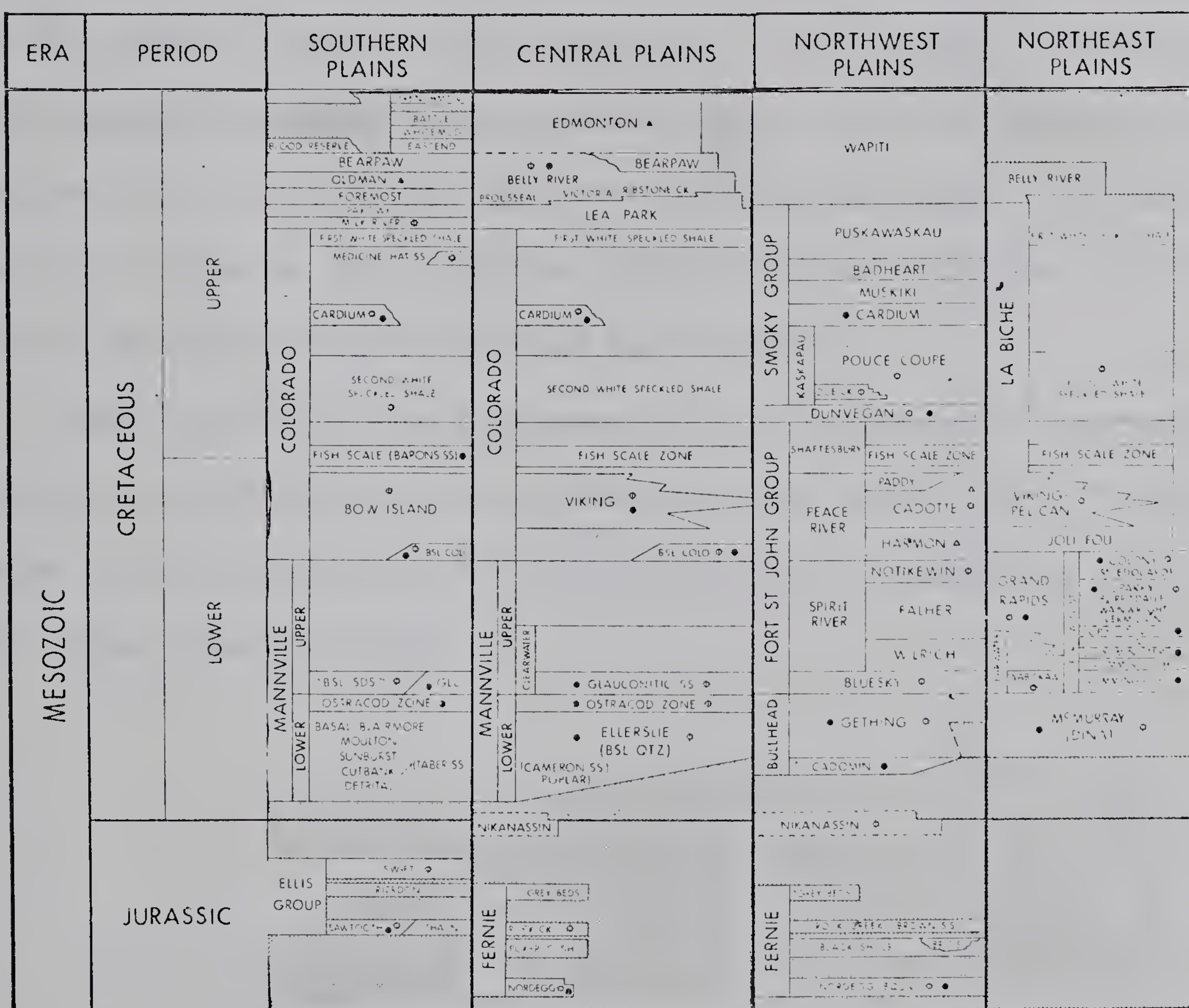
in further exploration. Two examples of the possibilities of this approach are discussed in Chapter 7.

The size of an oil or gas accumulation is the most significant feature of the pool from an economic standpoint, and is the end result of interaction of a number of geologic parameters. It is important to be able to define the size frequency distributions of pools within individual reservoir units so that estimates may be made of the degree of chance involved in exploring for pools in various reservoirs. If the size frequency distributions show anomalous features, it is desirable from an exploration standpoint to be able to identify the geologic conditions causing the anomalously large pools and to locate other occurrences of those geologic conditions in the basin.

If the frequency distributions for oil and gas reserves and for the plan area of pools are known to be consistent, the relationship between the two parameters may be defined for pools in a particular reservoir horizon, and some form of scatter plot and regression analysis will provide a basis from which area can be related to reserves or vice versa. Then, for a known economic minimum reserves level, the area required for a pool of minimum size in the target reservoir horizon can be calculated and used in conjunction with the known well density as an exploration criterion. Another parameter useful in the exploration for and development of a pool is the probable azimuth of elongation (trend) of the accumulation, which can be found from an analysis of the pools previously discovered in the target reservoir.

All of these proposed uses of data analysis presume that exploration for oil and gas in the target horizons is at a relatively mature stage, i.e. that the geology is well known, that a significant number of oil and gas accumulations have been discovered, and that further development will only partly modify established relationships. This appears to be a reasonable assumption for petroleum exploration in Cretaceous and Jurassic rocks of the Western Canada Sedimentary Basin.

TABLE OF CRETACEOUS AND JURASSIC FORMATIONS
ALBERTA



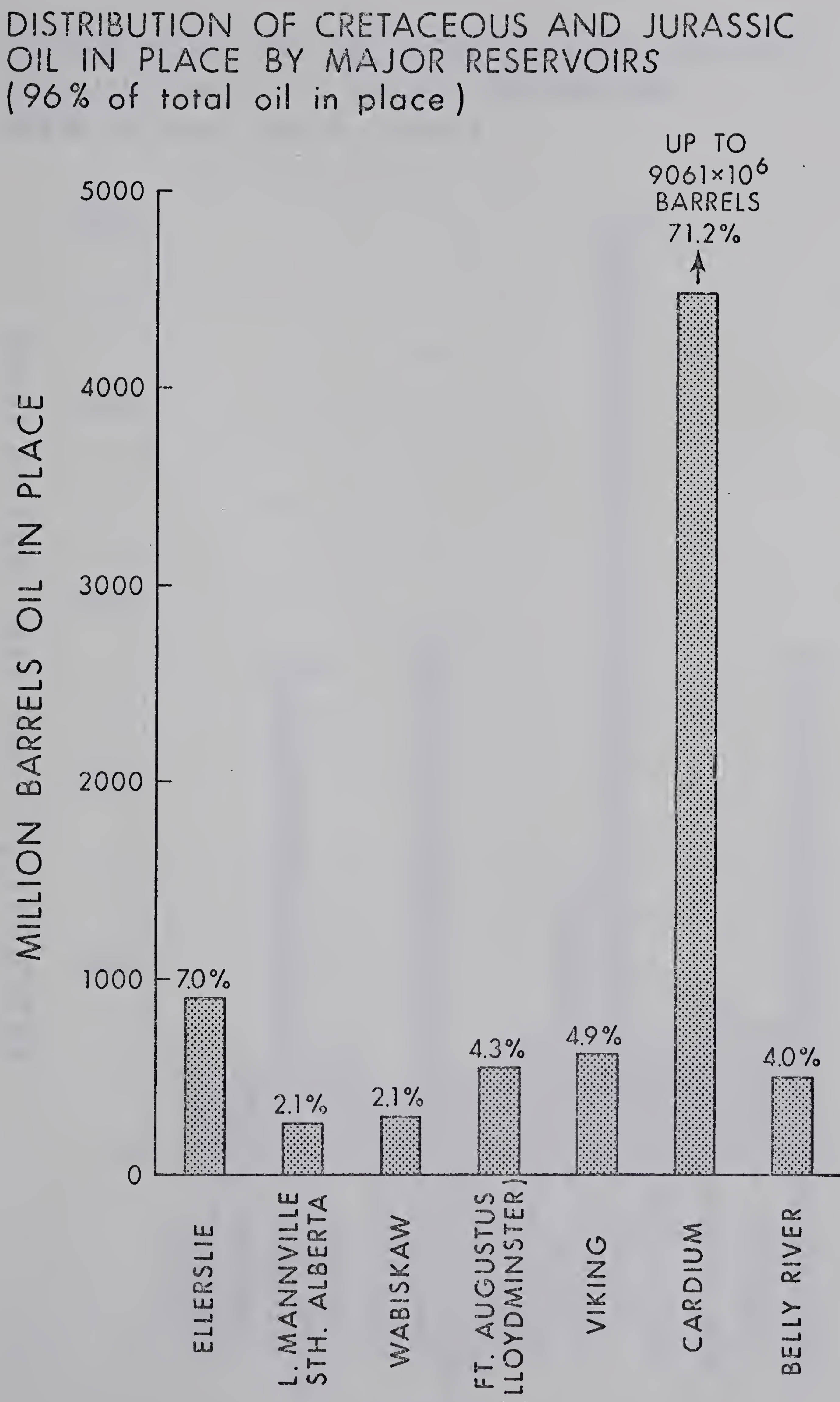
OIL AND GAS CONSERVATION BOARD CALGARY ALBERTA 1970

FIGURE 6

Major Cretaceous and Jurassic Oil and Gas Reservoirs

Size frequency distribution curves for Cretaceous and Jurassic oil and gas pools were plotted for all the major reservoir formations in Alberta. The distinction of "major" reservoirs was based largely on the total in-place oil or gas reserves, and partly on the number of pools in the reservoir. For instance, the Medicine Hat Sandstone contains large reserves of gas but these occur in only one pool so no statistical analysis could be performed. Figures 7 and 8 are based on data from the CRETPET file and show the distribution of oil and gas by "major" oil and gas reservoirs.

More than 71% of the Cretaceous oil is contained in the Cardium Formation and 80% of this is contained in the Pembina pool. This large size differential must be considered when comparisons are made with other groups of pools.



DISTRIBUTION OF CRETACEOUS AND JURASSIC OIL IN PLACE BY MAJOR RESERVOIRS (96% of total oil in place)
MILLION BARRELS OIL IN PLACE
0
1000
2000
3000
4000
5000
UP TO 9061×10^6 BARRELS 71.2%
7.0%
2.1%
2.1%
4.3%
4.9%
4.0%
ELLERSLIE
L. MANNVILLE STH. ALBERTA
WABISKAW
FT. AUGUSTUS (LLOYDMINSTER)
VIKING
CARDIUM
BELLY RIVER

FIGURE 7

DISTRIBUTION OF CRETACEOUS AND JURASSIC GAS IN PLACE BY MAJOR RESERVOIRS (94% of total gas in place)

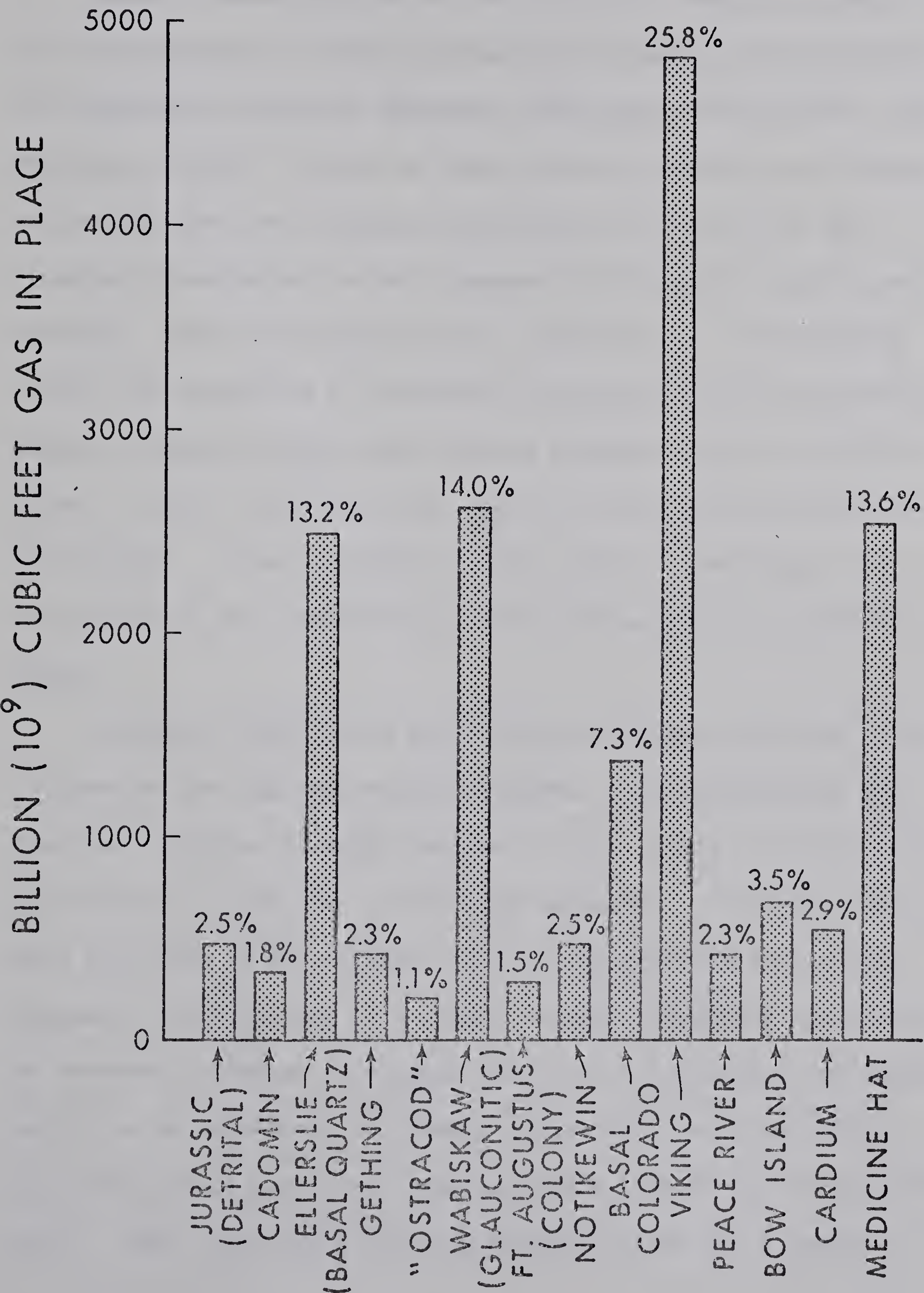


FIGURE 8

CHAPTER 2. SIZE MEASUREMENTS ON CRETACEOUS OIL AND GAS POOLS

Introduction

Several recent studies on the size of oil and gas accumulations have concentrated on analyzing the size frequency distribution of the hydrocarbon reserves (Kaufmann, 1964; Drew and Griffiths, 1965; McCrossan, 1969). In each of these studies, it has been inferred or assumed that the frequency distribution of the oil or gas reserves approximates to the lognormal distribution function and graphical plots have supported this observation. The reasoning behind the assumption of lognormal distribution has been based on a general comparison with other natural phenomena such as particle sizes, rainfall variations etc. which are known to be lognormally distributed. It was possible in this study to investigate the assumption of the lognormality of oil and gas pool sizes with a large sample.

McCrossan (1969) found best agreement between observed size frequencies and the theoretical lognormal distribution when the pools were plotted by major reservoir units, using an estimate of the reserves in the pool as the size parameter. With the amount of data available in the CRETPET file, it was possible to test the frequency distributions of a number of size parameters in addition to reserves estimates. The data for all the Cretaceous and Jurassic pools can be considered as a whole or the data can be separated according to the particular reservoir unit (Ellerslie, Viking, Cardium, etc.). Then, for each of these groupings, there are a number of size

measurements (e.g. oil reserves, gas reserves, plan area, major axis length) for which the frequency distribution can be tested statistically for lognormality.

In the study, the reserves value used was the calculated total oil or gas in place in the pool rather than an estimate of recoverable oil or gas. This in-place measure of reserves is most acceptable as an indicator of the size of the natural hydrocarbon accumulation in a geological sense because it is not affected by such unrelated and economically dependent factors as the recovery fraction.

Tests for Lognormality

Kolmogorov-Smirnov

Statistical tests which may be used to evaluate the "goodness of fit" of a sample frequency distribution to a postulated theoretical frequency distribution are the Kolmogorov-Smirnov test and the chi-square (χ^2) test (Sokal and Rohlf, 1969). The Kolmogorov-Smirnov test is more rigorous as it compares the theoretical cumulative frequency with the sample cumulative frequency at each class boundary from the minimum to the maximum class. For each specified significance level (.01, .05, or .10) there is a critical value for the difference in cumulative frequencies above which the theoretical distribution is rejected. However, the Kolmogorov-Smirnov test is difficult to apply and the conclusions are less valid where the mean and variance of the theoretical distribution are calculated from the sample (Lilliefors, 1967), as is the case for all examples in this study.

As a routine procedure, the computer program to calculate sample frequency distributions and plot histograms for different parameters included a subroutine which tested the sample distribution for normality (or lognormality) by the Kolmogorov-Smirnov test. In no case was there a significant indication (> 0.50 acceptance) that the sample distribution was lognormal.

Chi-square (χ^2)

A second choice of test is the "chi-square" (χ^2) method which is a more robust test but consequently does not have the exactness of the Kolmogorov-Smirnov test (Sokal and Rohlf, 1969). The "chi-square" method is explained clearly in many texts, and Krumbein and Graybill (1965, p. 175) discuss the application of the test where the parameters of the theoretical density function must be estimated from the sample. Further complications introduced in this study are the arbitrary lower limits set in the data collection process (0.5×10^6 barrels of oil in place, 5×10^9 cubic feet of gas in place) which cause a truncation of the sample frequency distribution. A method suggested by Cohen (1959) was used to calculate estimators of mean and variance for the theoretical density function from the truncated sample frequencies.

The range of transformed (to natural logarithms) sample values was divided into K intervals such that, if the sample were taken from a normal distribution, the probability of an observation occurring in any one of these intervals was the same and was equal to 1/K. For any group of pools being tested, the expected frequency for each of the K intervals was N/K where N was the number of pools

in the sample. The sample was then arranged into the K classes and the observed frequencies for each class were calculated. The χ^2 statistic was then computed using the relationship

$$\chi^2_{sample} = \sum_{i=1}^{K} \frac{[\text{Observed frequency (i)} - \text{Expected frequency (i)}]^2}{\text{Expected frequency (i)}}$$

To evaluate the statistic, the number of degrees of freedom was calculated from

d.f. = (K-1)-2

where K = number of classes.

The estimation of the two parameters of the theoretical density function (mean and variance) from the sample frequencies reduces the number of degrees of freedom by the extra 2. Using the number of degrees of freedom and the desired level of significance (.05, .10, .25), a value (χ^2_{table}) was read from the χ^2 tabulation. Then if χ^2_{sample} was greater than χ^2_{table}, the hypothesis that the sample was taken from a lognormal distribution could not be accepted at the specified level of significance.

Example of "Chi-square" Test

The size frequency histograms plotted for this study were examined, and it was decided that the histogram of the natural logarithm values of oil reserves in place for all Cretaceous and Jurassic oil pools in Alberta most closely approximated the shape of a normal (Gaussian) density function. The data were then used in a "chi-Square" test as

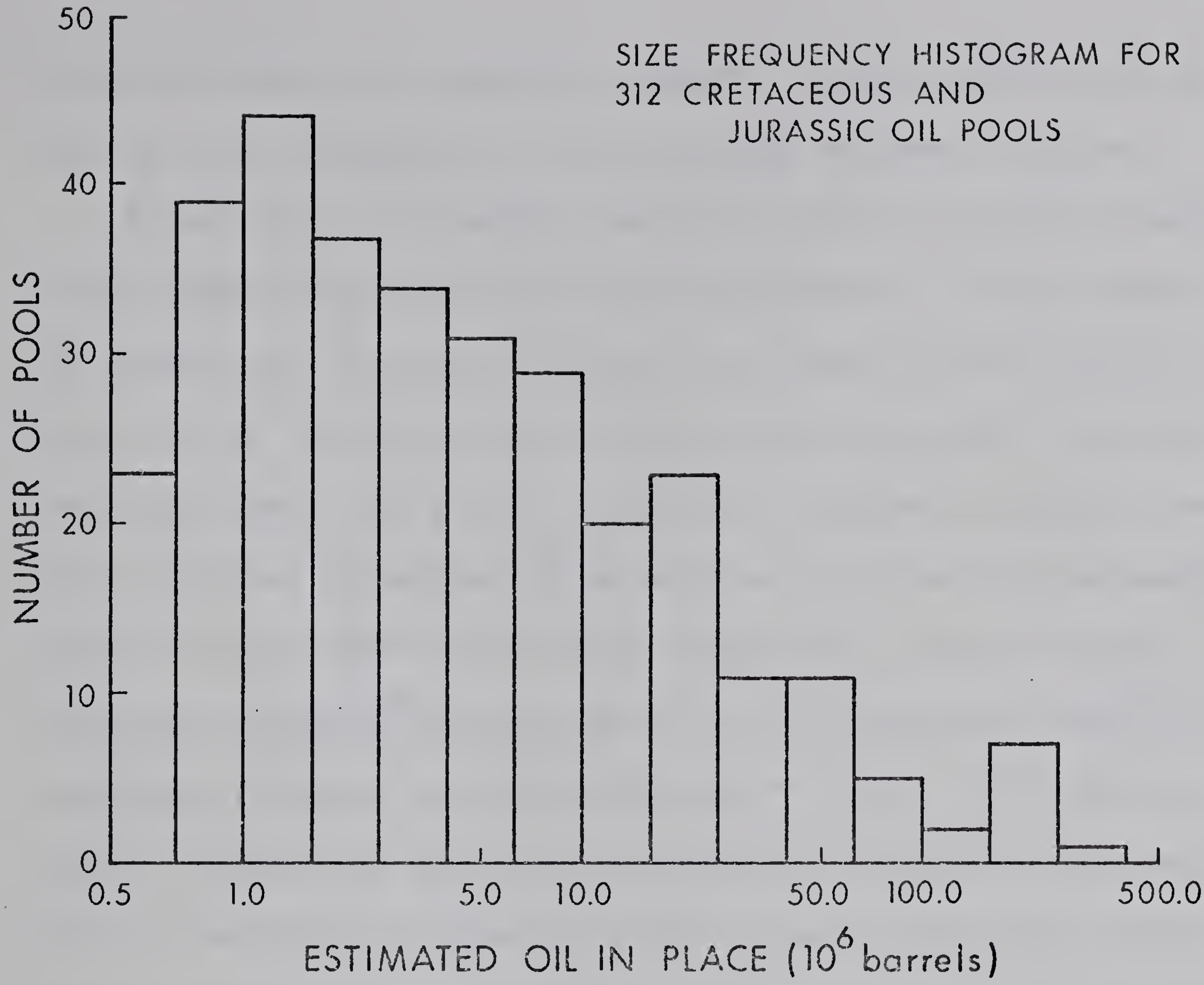
outlined above and the results are shown in Figure 9. The ultimate result is that the hypothesis of normality is not acceptable.

Discussion

Two conclusions may be drawn from this rejection:

1. Oil and gas pool sizes are not lognormally distributed but conform to some other exponential type distribution function (e.g. Pareto-Levy, suggested by Kaufmann, 1964; Gamma, James and Krumbein, 1969).
2. The data used contain too many approximations due to external factors (economic, political) to conform to formal statistical tests.

Kaufmann (1964) considered that the lognormal and Pareto-Levy functions were particularly adapted to the description of oil and gas field sizes primarily because (a) the shapes generated by these functions were visually similar to plotted histograms of oil and gas field sizes, (b) there was some basis for comparison with other natural phenomena which followed one of these functions, and (c) the lognormal function, in particular, was easy to use requiring only two parameters (mean and standard deviation) for its definition. In subsequent work by Drew and Griffiths (1965) and McCrossan (1969), a lognormal function was assumed largely on the basis of (a), and the practical consideration of (c). The shapes of the frequency distributions shown by the oil and gas pool sizes in this study conform to the shapes of a Pareto-Levy or a truncated lognormal density function. As has been shown, there is no firm



Estimated parameters (after correcting for truncation

Mean $\hat{X}$	=	1.464 (antilog 4.32 x 10^6 barrels)
Standard Deviation $\hat{\sigma}$	=	1.158 (antilog 3.18 x 10^6 barrels)
Number of Classes K	=	37
Sample Size N	=	312
Expected Frequency N/K	=	8.4

$$\chi^2_{sample} = \sum_{i=1}^{K} \frac{(Freq_{obs} - Freq_{exp})^2}{Freq_{exp}} = 84.8$$

Degrees of Freedom (d.f.) = (K-1)-2 = 34

From Tables (Krumbein and Graybill, 1965)

Significance Level	.10	.25	.50
χ^2_{table} (34 d.f.)	24.0	28.2	33.3

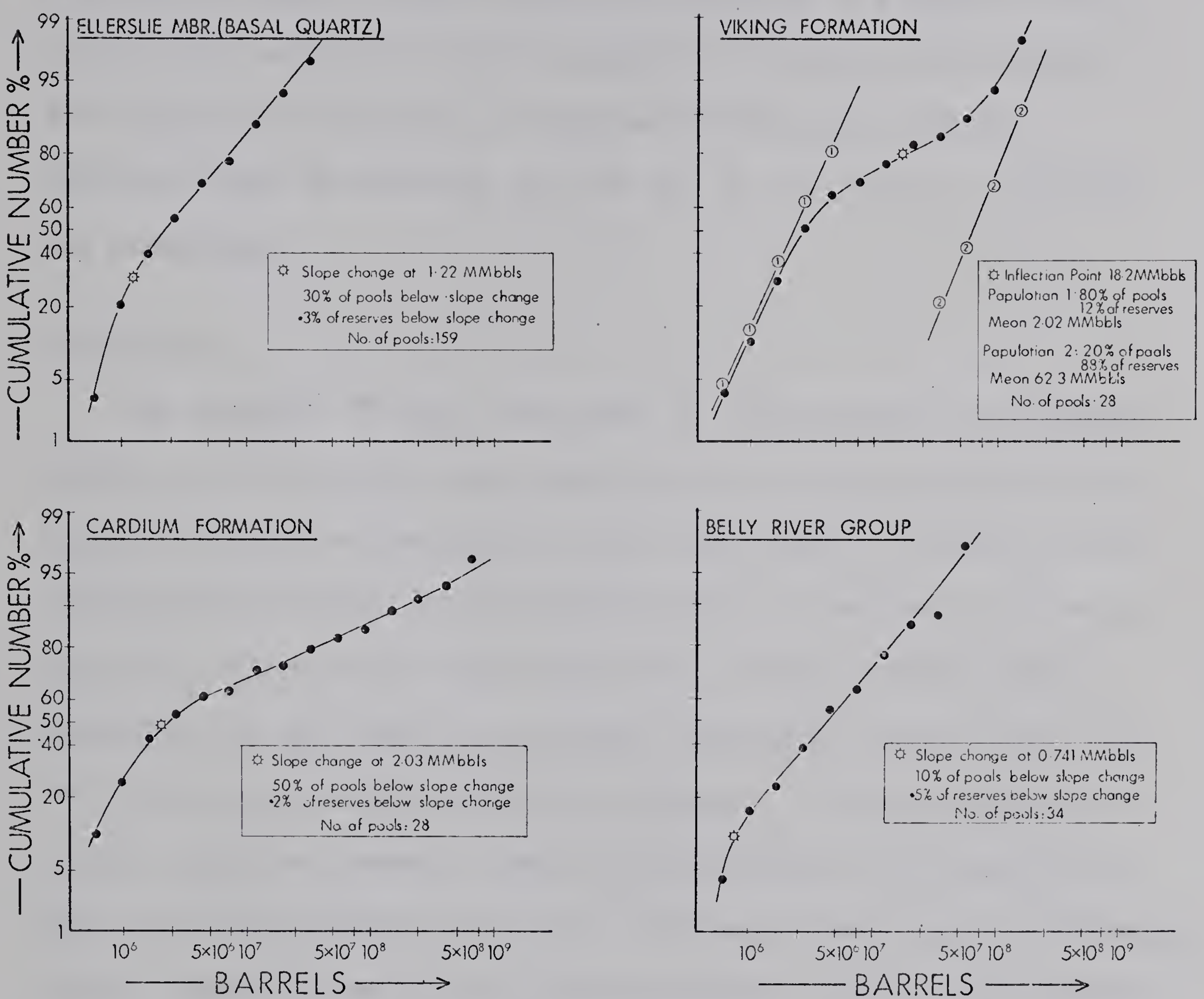
The hypothesis that the sample is drawn from a normally distributed population cannot be accepted.

FIGURE 9

statistical basis for assuming a lognormal density function but no test has been attempted for the Pareto-Levy or gamma functions.

Acceptance of a lognormal function is highly desirable because of its simple form defined by only two parameters. A last resort for supporting a lognormal function is to compare graphically the shapes of the frequency distributions of the more useful parameters (reserves, areas, etc.) with a theoretical lognormal function curve. The best visual comparison can be obtained by converting the sample data to a logarithmic base (natural logarithms), calculating the cumulative frequency distribution of the log values, and plotting this cumulative frequency on "probability paper" (Hazen, 1913; Harding, 1949). "Probability paper" has an ordinate graduated so that each division represents an equal area under a normal (Gaussian) density function curve, on an arithmetically scaled abscissa. On this paper, a theoretical lognormal distribution function will plot as a straight line, thus the more closely the sample curve resembles a straight line, the more closely it approximates a lognormal distribution.

Examination of "probability-paper" graphs of pool size measurements shows that most points do fit the straight-line shape and that the deviations from lognormality occur primarily in the tails of the distributions. These irregular values in the very large and very small sizes are the main reason for the non-acceptance of lognormality in the statistical tests. It is therefore justifiable to assume that the sizes of oil and gas pools are, in the main, lognormally distributed.



CUMULATIVE FREQUENCY PLOTS OF
IN—PLACE OIL RESERVES FOR MAJOR RESERVOIRS

FIGURE 10

Frequency Distributions of Oil Reserves

Cumulative frequency plots on probability paper of in-place reserves for pools in major reservoirs are shown in Figure 10. All of the plots exhibit an overall tendency to conform to the straight line shape, which indicates a lognormal distribution, and the deviations from the straight line are due to two effects - truncation and bimodality.

Truncation

The truncated straight line shape is characteristic of Ellerslie, Cardium, and Belly River pools, and the point at which truncation is evident is marked on the plots as the slope change. In each case the straight line portion of the cumulative curve is defined by the major proportion of the pools in the reservoir. If this straight line is projected into the smaller size ranges, the quoted reserves value for the smaller pools appear to be over-estimated. The pools that occur in this region are generally small, being defined by only one or two wells, and the assigned reserves are calculated from a set of arbitrary rules. Apparently one or more of the parameters used in the estimates are too high.

The over-estimation of oil reserves in the small Belly River pools can be attributed directly to the apparent over-estimation of the pool areas, as indicated by the truncation of the cumulative frequency plot in the small size range in Fig. 12. Pool plan area curves for the Ellerslie and Cardium pools do not show any truncation (Fig. 12) and therefore the over-estimation of oil reserves in small

pools must be caused by high values of some other parameter such as oil zone thickness, porosity, or water saturation. Average values for the oil column which are too high may be the cause of the truncation in the Ellerslie Member pools, because the Ellerslie pools characteristically have thick oil columns, which would tend to produce optimistic estimates.

The straight line portions of the curves of the Ellerslie, Cardium, and Belly River pools are well defined by most of the pools recorded in the study, in particular by the larger pools. It is reasonable to expect that future oil pools discovered in these reservoirs will follow the same size distribution patterns, i.e. the sizes will plot on the straight lines. The cumulative frequency graphs can then be used as a predictive tool in an oil exploration program to indicate the probability of finding an oil pool greater than any given size in a particular reservoir unit.

For example, if an oil pool is discovered in an Ellerslie Member reservoir, the probability that the pool will contain more than 10^7 barrels of oil in place is .15. The probability of a Cardium Formation pool containing more than 10^7 barrels of oil in place is .32, and for a Belly River Group pool, the probability is .27.

Bimodality in Viking Formation Pools

It is obvious from Fig. 10 that pools in the Viking Formation do not form the usual straight line cumulative curve, but tend towards two straight line segments. This phenomenon of bimodality

was observed and discussed by McCrossan (1969) and his observations have been verified and extended by this study. McCrossan quoted work by Harding (1949) and Cassie (1954) in which the straight line segments of the cumulative frequency curve were related to different "populations" of animals, e.g. fish of different ages (Cassie, 1954). This concept of populations was applied to groups of oil and gas pools, and for oil pools in the Viking Formation, a large and small population can be defined. The point of inflection separating the two populations is at 18.2×10^6 barrels of oil in place.

In this study, considerable emphasis was placed on the identification of the factors that cause the development of different populations of pools. McCrossan (1969) suggested that petroleum reserves in pools in the small size population were underestimated because of a lack of detailed knowledge of the reservoir. However, the Viking Formation has been tested for oil and gas in a large number of wells and it was felt that there was some geological factor causing the differentiation. If the factor could be identified, then it could be used to explore for the large size population pools in the Viking Formation. Its geological significance is discussed in Chapter III.

Frequency Distributions of Gas Reserves

Cumulative frequency curves of in-place gas reserves for pools in the major Cretaceous reservoir horizons (excepting the Medicine Hat sandstone pool) are plotted in Fig. 11. In general, the curves do not approximate to the lognormal straight line as closely as did the curves for oil pool reserves, and the tendency to bimodality is more common. These features probably reflect less maturity in the exploration for and delineation of gas fields and possibly some inconsistencies in reserve estimation procedure.

The curves for the Ellerslie Member pools and the Viking Formation pools approximate to the straight line form with truncation at the smaller end, but exhibit some variations which are difficult to explain. Ellerslie Member pools with in-place gas reserves from 7×10^9 to 3×10^{10} cubic feet are smaller than would be expected if the straight line defined by the upper 15% of pools is correct. If the natural distribution is truncated lognormal as suggested by the oil pool curves, then the gas pools with reserves which lie in tha shaded area of the graph contain reserves greater than now assigned.

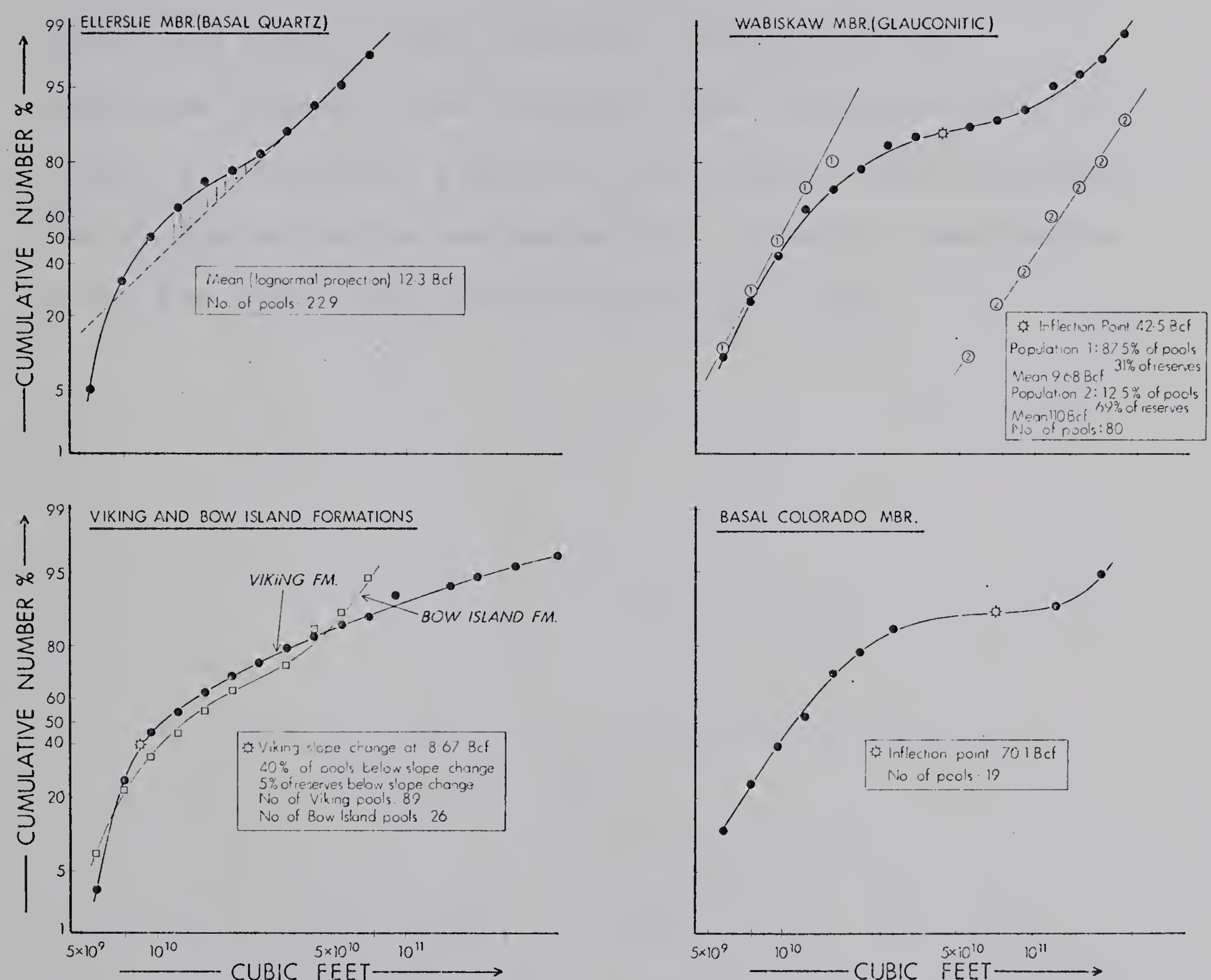
The cumulative frequency curve for Viking Formation gas pools approximates a very gentle curve for the larger 50% of pools and is truncated at its lower end. Such irregularities as the gentle curve in the Viking Formation pools graph and the "underestimated" part of the Ellerslie Member pools plot can be attributed to the still developing exploration pattern for gas in Alberta. Until recently,

the areal extent of many gas pools was not as fully delineated as that of oil pools because of economic factors, e.g. the small demand for the sale of natural gas, and as a result, minor irregularities in the size distribution patterns can be expected, until exploration reaches a more mature stage. It appears that the ultimate patterns will be represented by truncated lognormal distributions.

The other three major gas reservoirs (Bow Island, Wabiskaw, Basal Colorado) appear to have clearly bimodal distributions. The two populations are particularly well defined by the 80 pools in the Wabiskaw Member and its equivalents and this curve has been dissected using the Cassie (1954) method. As shown on the diagram, Population 1 accounts for 87.5% of the pools by number but only 31% of the total reserves. Obviously pools in Population 2 with mean reserves of 110×10^9 cubic feet gas in place are more attractive as exploration targets. Attempts to identify the distinctive geological properties causing the formation of the large population pools in the Wabiskaw Member are presented in Chapter III.

Basal Colorado and Bow Island Pools

Two pools form the larger population in the Basal Colorado Member, and both these pools are in the Cessford field of southern Alberta. The sample size of 19 pools does not allow conclusions to be drawn from the shape of the cumulative frequency distribution with any degree of confidence. It is suggested, therefore, that the Cessford area may represent a unique combination of a widespread sand development and a favourable trapping mechanism for the gas, and



CUMULATIVE FREQUENCY PLOTS OF
IN-PLACE GAS RESERVES FOR MAJOR RESERVOIRS

FIGURE 11

that these conditions may not be repeated in the remainder of the province.

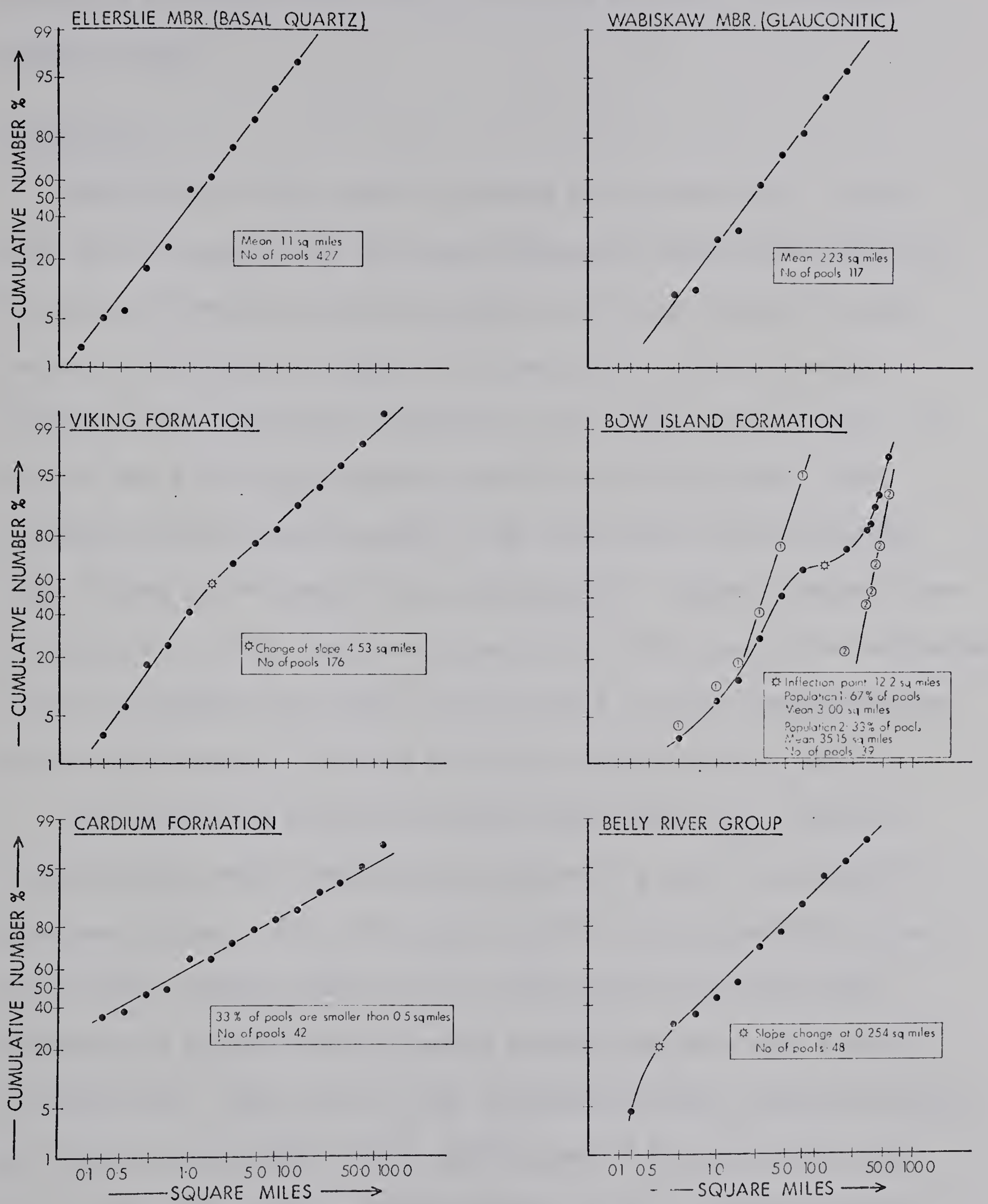
Gas reserves for pools in the Bow Island Formation also plot as a bimodal curve but these pools are volumetrically the least significant group of pools considered. Inspection of the cumulative frequency curve for areas of Bow Island pools (Fig. 12) reveals a corresponding bimodality which suggests that stratigraphic factors distinguish the two populations. No further investigation of the Bow Island pools was conducted in this study.

Frequency Distributions of Pool Plan Areas

In Fig. 12 the most obvious feature of the cumulative frequency plots is their regular straight line character, indicating that for most reservoirs the plan areas of pools have a lognormal frequency distribution. There is no distinction made between oil and gas pools so the plan areas plotted will probably reflect aspects of the depositional history of the reservoir rock.

In this regard it is interesting to compare Ellerslie Member areas with Wabiskaw Member areas. Both plot as well defined straight lines with similar slopes - the distributions are lognormal with similar standard deviations. However, the mean plan area for Wabiskaw Member pools is twice the mean for Ellerslie Member pools. In addition, the average oil and gas zone thicknesses for Wabiskaw Member pools are less than those for the Ellerslie Member pools (Appendix IVf), thus Wabiskaw Member pools are areally larger but thinner than Ellerslie Member pools.

These features are consistent with the depositional environments proposed for the two sand units (Williams, 1963). The Ellerslie Member reservoirs were deposited in deep valleys cut into the pre-Cretaceous surface and are sandstones of point-bar or channel fill origin, restricted areally, but locally very thick. Sand bodies of the Wabiskaw Member were deposited on a surface with much lower relief during a widespread marine transgression and are of a coastal plain non-marine or near-shore marine origin. Sand bodies formed in these environments would be expected to be larger areally, more



CUMULATIVE FREQUENCY PLOTS OF
POOL PLAN AREA FOR MAJOR RESERVOIRS

FIGURE 12

extensive but thinner than those resulting from the infilling of eroded valleys.

Truncation

When an oil or gas pool is defined by only one well, a pool plan area is assigned by the Energy Resources Conservation Board on the basis of previous experience with the lateral extent that the reservoir is likely to attain. For reservoirs that follow the straight line (lognormal) form down to very small areas in Fig. 12, such as the Ellerslie, Wabiskaw, Cardium and Viking pools, the assigned plan area would appear to be consistent with the maximum size allowed by the overall size distribution. However, where there is truncation in the low size ranges (Belly River pools) the estimated areas are probably too high, and the effect of this over-estimation on the resulting oil reserves values was discussed on p. 65.

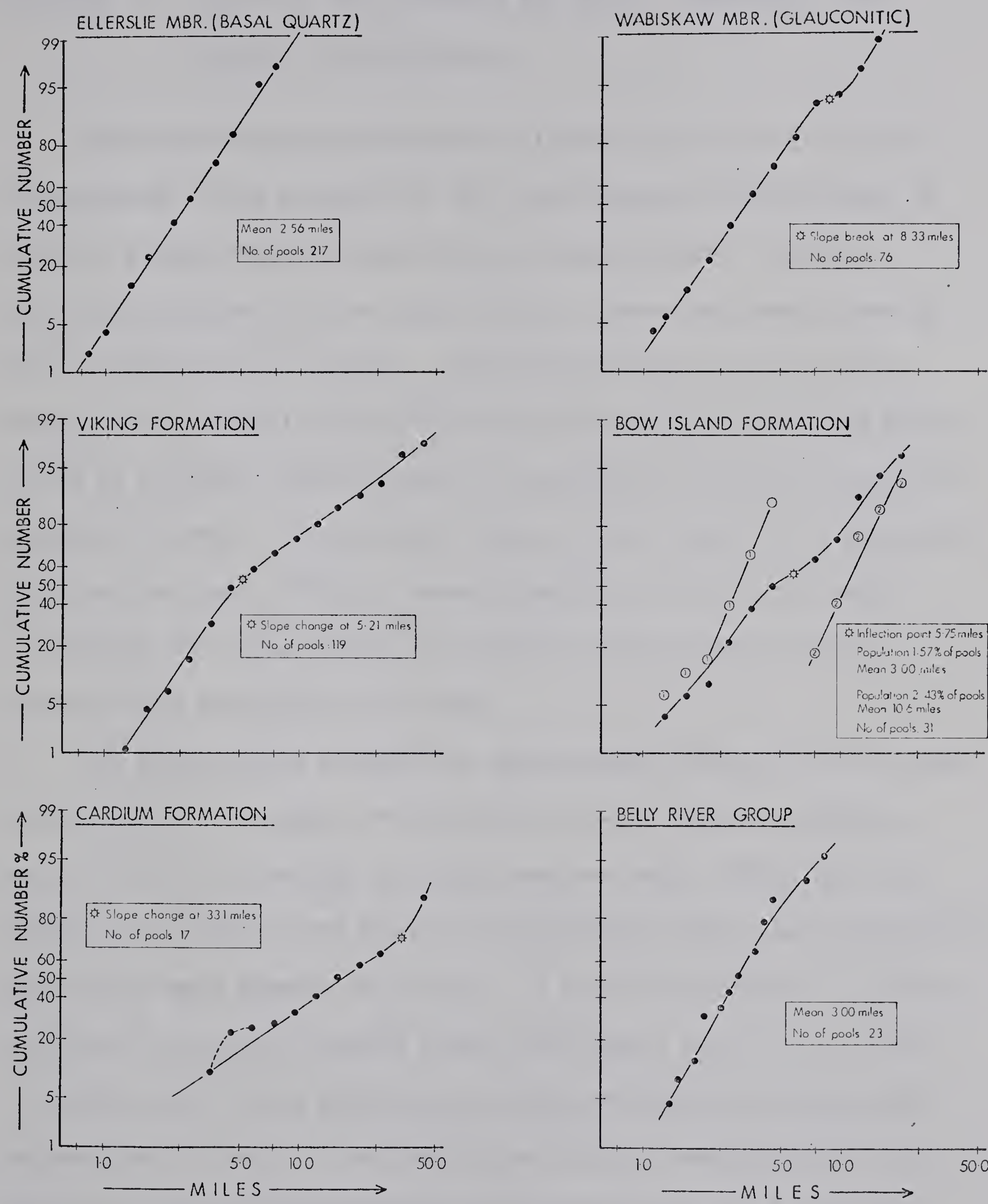
The cumulative curve for Cardium pool areas has a very low angle of slope which indicates that there is a wide dispersion of plan area values. It is felt that the wide size dispersion is due to the very elongate shape of the Cardium pools (and the actual Cardium sand bodies) which allows a greater and more even spread of pool sizes. The curve in Fig. 12 predicts that a large proportion of Cardium pools (33%) will be smaller than 0.5 square miles and this includes the pools which at present have an assigned area of 0.25 square miles. It would appear from the cumulative curve that these small Cardium pools have actual areas less than 0.25 square miles.

Larger Viking Formation pools are generally more elongate than the smaller pools and this difference may be responsible for the lower angle of slope of the cumulative curve for large pool plan areas (Fig. 12).

Frequency Distributions of Major Axis Lengths

The plots of cumulative number frequency of major axis lengths of pools are shown in Fig. 13. The curve shapes are very similar to those for pool plan area (Fig. 12) as expected, because the plan area of a pool is very dependent on the length of the major axis. Scatter plots of the logarithm of major axis length against the logarithm of pool plan area for most of the reservoir units studied, showed a high degree of correlation (correlation coefficient $R > 0.90$) and the greatest scatter of points was for small lengths and areas. This relationship must be considered in multivariate analysis where only one of the variables should be used.

A notable feature of these cumulative curves is the lack of truncation effect in the smaller sizes. Axial lengths were measured in this study only if a pool was well enough defined by drilling so that an isopach map could be drawn of the oil or gas zone. There was no arbitrary assignment of axial length to poorly defined pools, and therefore the truncation effect noted in previous cumulative curves may be confidently assigned to the over-estimation or reserves of areas in pools not well defined by drilling.



CUMULATIVE FREQUENCY PLOTS OF
MAJOR AXIS LENGTH FOR MAJOR RESERVOIRS

FIGURE 13

CHAPTER 3. VIKING OIL AND WABISKAW GAS POOLS - ANOMALOUS SIZE FREQUENCY DISTRIBUTIONS

The best defined and statistically most significant anomalies encountered in the analysis of the size frequency distributions in Chapter 2 were those in the Viking oil pools (p.66) and the Wabiskaw (Glauconitic) gas pools (p.69), where two populations of pools appeared to be present. If some parameter or set of parameters which uniquely identified only the population of large pools could be defined, the efficiency of exploration in these reservoirs could be improved. The approach taken in this study is to group the pools on the basis of their known properties, isolate the group containing the larger pools, and identify the properties that characterize the group so isolated.

One method which attempts to group samples (pools in this case) on the basis of a number of variables is Q-mode factor analysis, used initially in geology by Imbrie and van Andel (1964) for the grouping of rocks on the basis of heavy mineral data, and subsequently applied to many aspects of geology. A limiting condition in factor analysis is that each sample (pool) must have a value for all the variables used in the analysis, so that correlations between null values are avoided. It was desirable in this investigation of the Viking oil pools and Wabiskaw gas pools that as many of the pools as possible be included, the number of variables used was limited because some measurements were not available for small pools.

The factor analysis program used was that of Klovan and Imbrie (1971), which calculates a series of factor solutions, each solution

using one less factor than the preceding one. The technique enables the analyst to choose a solution that produces the most significant grouping of samples and also accounts for a suitable percentage of the total variance.

Viking Oil Pools Study

Statistical Treatment

The most significant grouping of pools that could be derived from the Q-mode factor analysis of oil pools in the Viking Formation was obtained from a 4-factor varimax solution which accounted for 95% of the total variance. The percentage of the total variance accounted for by each varimax factor is

Factor 1: 50%

Factor 2: 34%

Factor 3: 8%

Factor 4: 3%

Fig. 14 shows the factor 1 value plotted against the factor 3 value for each pool and a well-defined cluster of pools with high factor 1 values and low factor 3 values is evident. The variables (measurements) used in the factor analysis are listed below, and their contribution to factors 1 and 3 of the 4-factor solution, are shown graphically in Fig. 15.

1. Pool plan area
2. Oil reserves
3. Average oil zone thickness

4. Regional dip
5. Pay zone top elevation
6. Porosity
7. Water saturation
8. Oil gravity (API)

It is recognized that variables such as porosity and water saturation have "closed" ranges, i.e. are expressed as percentages, and this can distort factor analysis results. However, both variables have a limited range (porosity <.35, water saturation <.60) and also their complements (rock framework fraction, hydrocarbon saturation) are not used in the factor analysis, so that use of these "closed" variables will not produce spurious groupings.

In terms of the original variables, the cluster in Fig. 14 includes pools with a high elevation of the Viking pay zone, high porosity, and small size. The other pools which include all those in Population 2, as defined by the frequency analysis, have relatively low elevation and porosity, but vary considerably in size. The elevation of the pool and the average porosity alone do not distinguish among pools, as shown in Table V, thus it is the combination of variables which defines the groups.

There is, however, no obvious grouping of the large pools (Population 2) evident in the factor analysis results. Axial measurements were not included among the variables used in the factor analysis because axes cannot be defined for many of the small pools, but examination of the values for the Viking oil pools in Table V reveals that the axial elongation (major axis length/minor axis length) and

Q-MODE FACTOR ANALYSIS VIKING FORMATION OIL POOLS
(4 FACTOR VARIMAX SOLUTION)

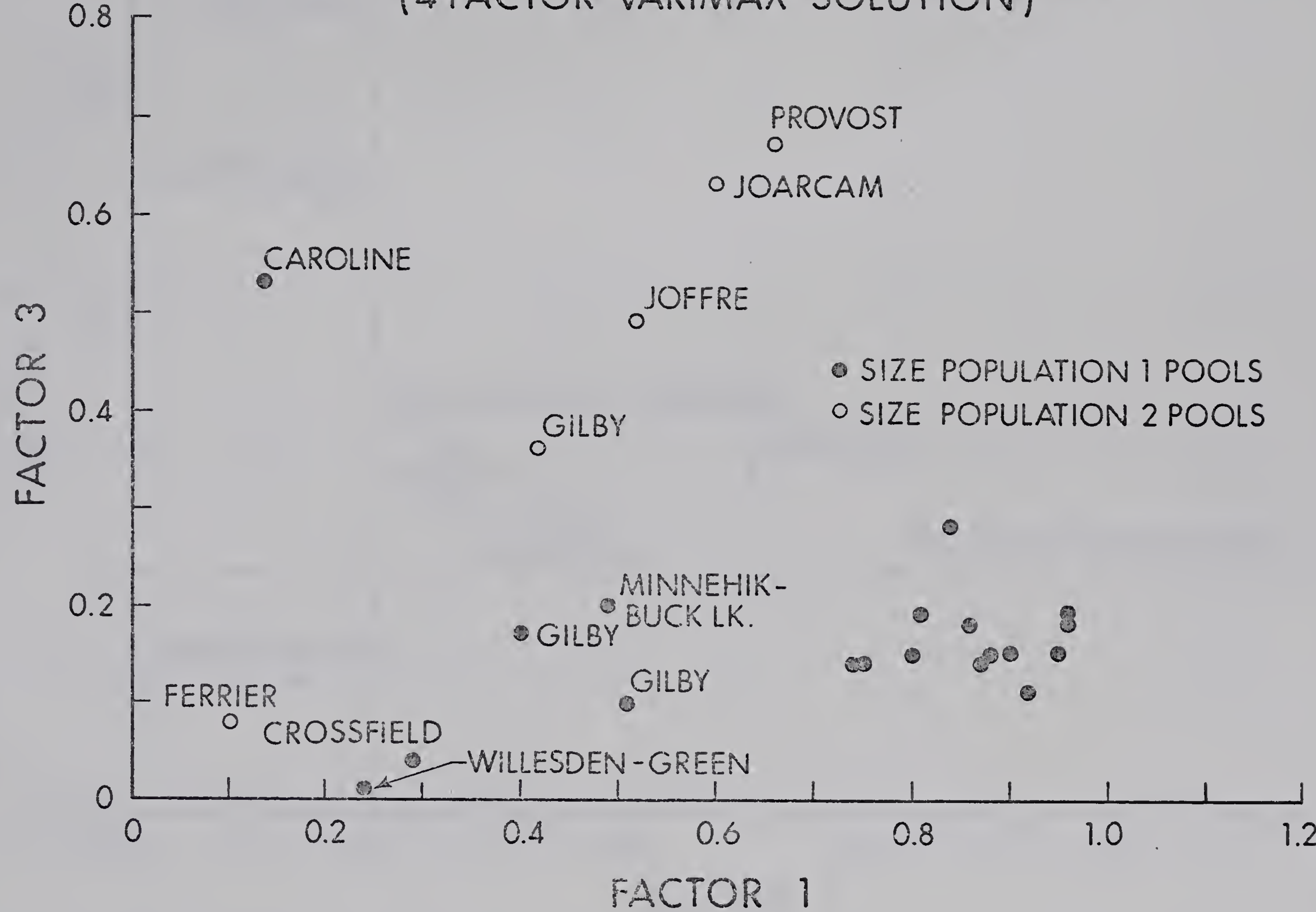


FIGURE 14

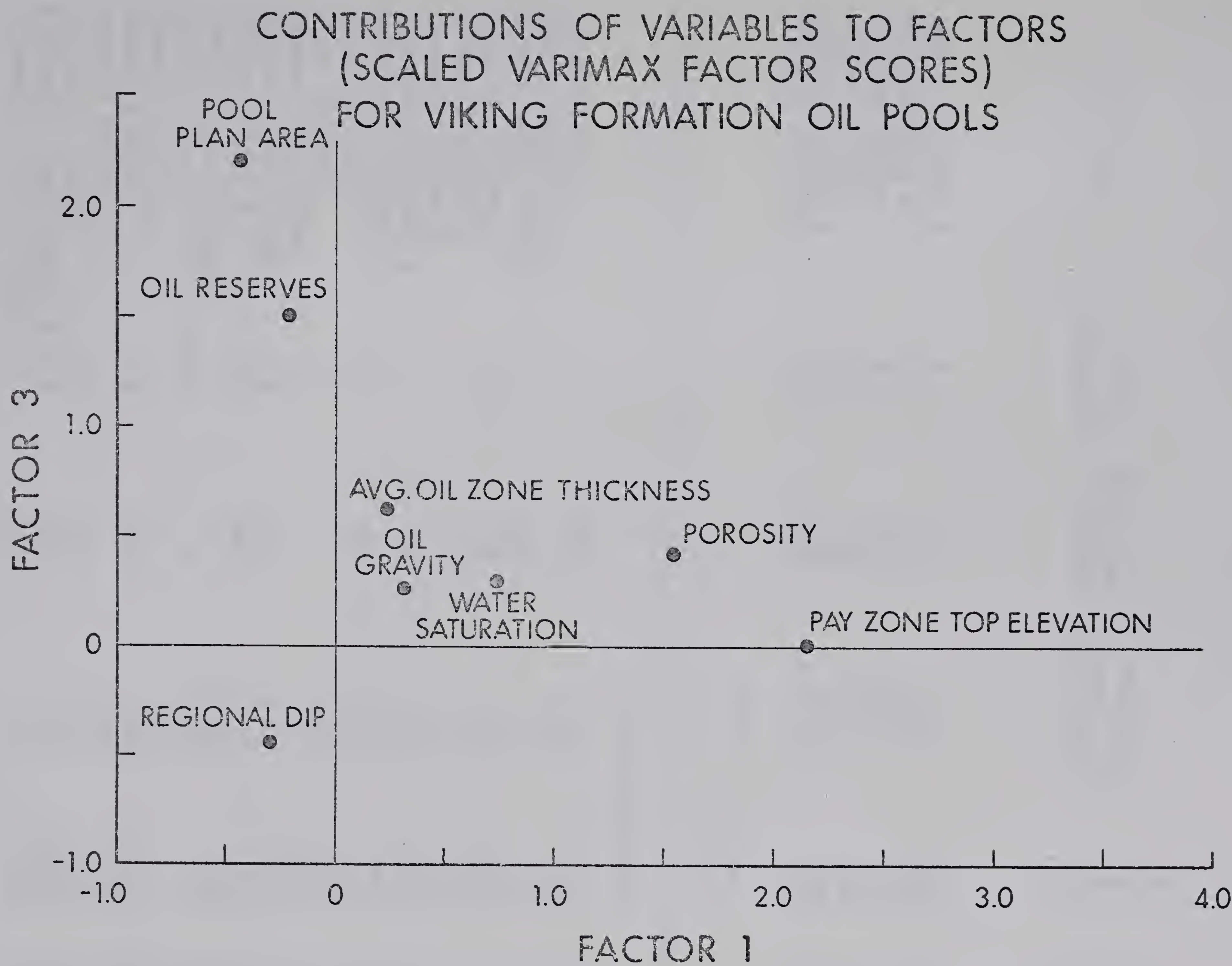

CONTRIBUTIONS OF VARIABLES TO FACTORS
(SCALED VARIMAX FACTOR SCORES)
FOR VIKING FORMATION OIL POOLS
POOL
PLAN AREA
OIL RESERVES
AVG. OIL ZONE THICKNESS
OIL
GRAVITY
WATER
SATURATION
POROSITY
PAY ZONE TOP ELEVATION
REGIONAL DIP
FACTOR 3
2.0
1.0
0
-1.0
-1.0
0
1.0
2.0
3.0
4.0
FACTOR 1

FIGURE 15

TABLE V

Pool Name	Axial Elongation	Major Axis Azimuth	Millions Barrels Oil in Place	Elevation	Porosity
Ferrier Viking A	7.8	118	20.0	-4822	.07
Gilby Viking A	11.7	114	38.4	-3080	.10
Joarcam Viking	8.5	152	221.0	-731	.20
Joffre Viking	13.8	116	80.1	-1966	.11
Provost Viking A	1.8	82	75.0	-364	.26
Provost Viking C	2.6	118	117.0	-295	.22
			88% of reserves		
			12% of reserves		
Battle Viking	3.4	176	2.68	-784	.15
Battle North Viking	-	-	1.51	-800	.15
Battle South Viking	1.0	166	3.16	-801	.15
Caroline Viking A	2.75	132	5.82	-4393	.13
Chigwell Viking A	-	-	1.11	-1730	.14
Chigwell Viking B	-	-	1.50	-1710	.13
Crossfield Viking A	-	-	0.53	-3387	.09
Fairydell Viking C	-	-	0.95	-425	.20
Gilby Viking B	5.7	111	15.00	-3180	.07
Gilby Viking E	-	-	0.83	-3431	.13
Giroux Lake Viking	-	-	3.78	-2027	.15
Joffre South Viking	2.4	112	1.25	-1155	.18
Killam Viking A	1.5	145	1.32	-262	.19
Kirkpatrick Viking A	-	-	10.00	-364	.26
Legal Viking	1.7	4	2.40	-477	.18
Minnehik Viking	-	-	1.67		.16
Peavey Viking	1.4	108	2.96	-464	.20
Provost Viking D	-	-	2.54	-336	.25
Provost Viking E	2.0	90	4.35	-336	.25
Willesden Green Viking A	3.3	122	2.61	-3743	.06
Wintering Hills Viking A	1.9	139	8.81	-418	.23

azimuth of the major axis appear to be highly significant. With the exception of the Provost Viking A and C pools, the axial elongations for the larger pools are much greater than those of the smaller pools. Also the larger pools (except Joarcam and Provost A) have very similar azimuths of the major axis whereas for the smaller pools the azimuths vary widely.

Stratigraphic Evidence

From an examination of these statistical results and after further searching the file for lithologic data, two natural groups of Viking oil pools emerge:

(a) The elongate pools in the deeper part of the basin (Joffre-Gilby-Ferrier area), trending approximately 20° south of east, with low-porosity and fine-grain-sand reservoirs, probably of shoreline or near shore origin;

(b) The less elongate, shallower pools (Camrose-Provost area), trending south to southeast, with higher-porosity and coarser-sand reservoirs which may have originated as reworked sands on offshore shoals.

These two groups, however, do not coincide with the two populations defined by the size frequency analysis indicating that the mode of deposition of the reservoir rock is probably not the sole controlling factor in the ultimate size of the oil accumulation.

When the detailed stratigraphy of the Viking oil pools was examined, it was found that all the large population pools occurred in extensive developments of the "main" Viking sandstone, whereas

the smaller population pools occurred in restricted sandstone lenses above, below, and laterally equivalent to the main sandstone. The "main" Viking sandstone is the thickest and most widespread unit in the Viking Formation and provides a much greater area in which oil can accumulate than the minor sandstones in the rest of the Viking Formation. The conclusion that the large oil pools occur only in the thickest sandstone in the Viking Formation is not very revealing but it does place an upper limit (10^7 barrels of oil in place, Fig. 10) on the reserves that could be expected in a pool in a minor Viking sandstone reservoir.

Hydrodynamic Conditions

Fluid potential distribution in the Viking Formation, and the effects of the resultant fluid flow pattern on the size of oil pools must also be considered. Hitchon (1969) mapped a closed fluid-potential low in the Viking Formation centering on the Gilby area (Fig. 16). In terms of the fluid-flow model of Toth (1963) and Freeze (1969), in which the fluid column in a basin is considered continuous, this fluid potential low will cause formation water in the Viking reservoir to flow laterally from all directions towards the "sink" in the Gilby area. Hitchon postulated that the driving force in the system was the osmotic pressure across the shale membranes between the low salinity Viking Formation water and the higher salinity waters of the Mannville sandstones below, and particularly the very saline waters of the deeper Devonian Woodbend Group reservoirs. An alternative interpretation of the anomalous

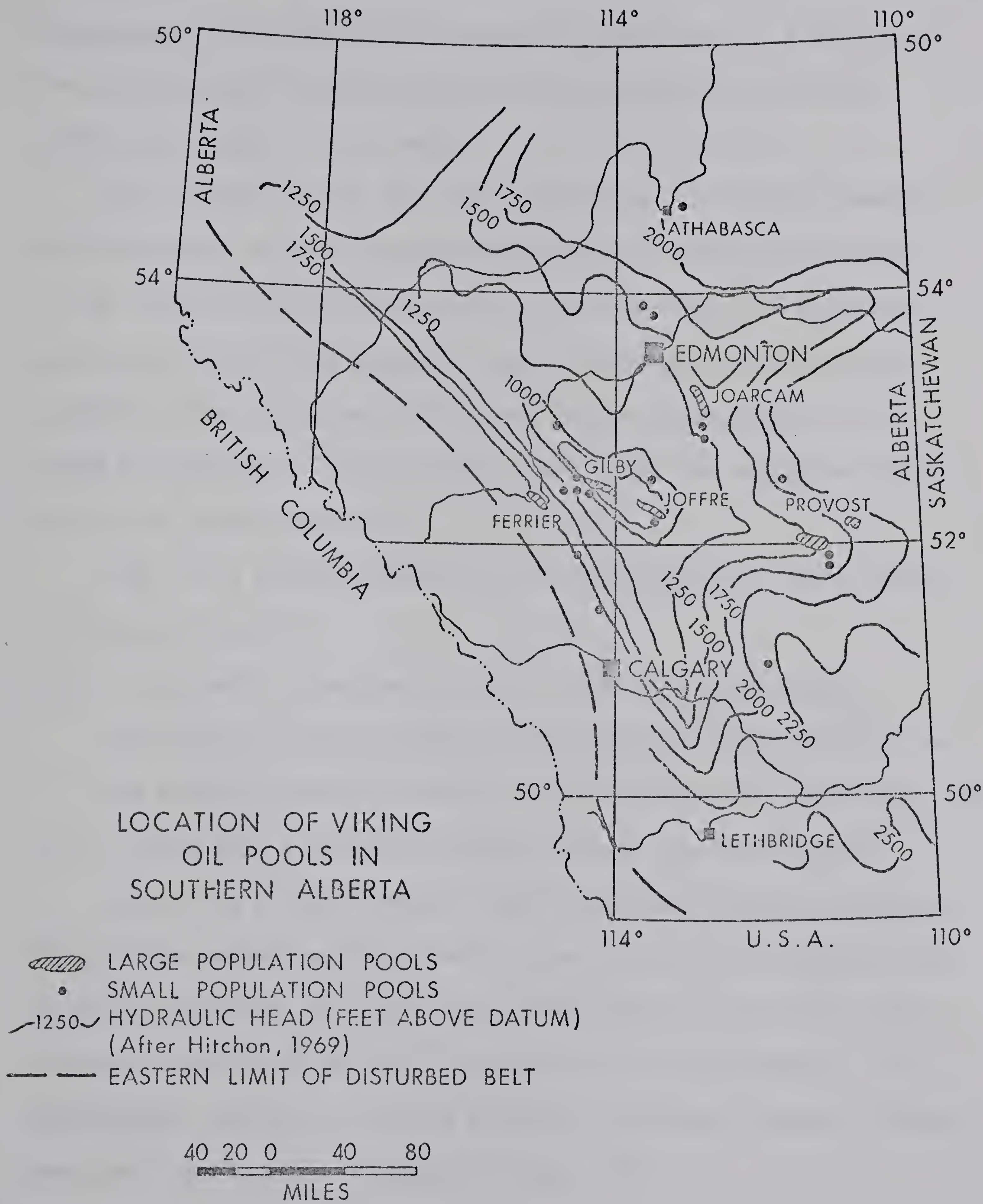

118°
114°
110°
50°
54°
52°
50°
114°
110°
ALBERTA
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
U.S.A.
ATHABASCA
EDMONTON
JOARCAM
GILBY
JOFFRE
FERRIER
PROVOST
CALGARY
LETHBRIDGE
1250
1500
1750
1000
2000
2250
2500
LOCATION OF VIKING OIL POOLS IN SOUTHERN ALBERTA
LARGE POPULATION POOLS
SMALL POPULATION POOLS
1250 HYDRAULIC HEAD (FEET ABOVE DATUM) (After Hitchon, 1969)
EASTERN LIMIT OF DISTURBED BELT
40 20 0 40 80
MILES

FIGURE 16

fluid potential in the Viking Formation in which 6 separate pressure systems were identified was presented by Harris et al. (1970), but the low density of control points in this study did not allow proper evaluation of this model.

The regional dip of the Viking Formation is uniformly towards the south-west so that the effective buoyancy forces acting on oil in the reservoir will be directed to the north-east. On the north-east side of the fluid potential low, the buoyancy force would be opposed by the hydrodynamic flow, and larger accumulations of oil could be expected in stratigraphic traps where the sandstone "shales out" in an up-dip direction.

Fig. 17, a pressure-depth plot for the Viking oil pools, shows two groups of pools:

(a) a group with a pressure gradient lower than hydrostatic, consisting of pools located in the centre of the potential low and pools at shallower depths to the north-east of the "sink", and

(b) a group with a pressure gradient greater than hydrostatic, consisting of pools in the "sink" and those to the south-west.

Most of the large population pools occur in (a), which supports the previous reasoning, but the Ferrier Viking pool in group (b), with in-place reserves of 20 x 10^6 barrels of oil is an exception. The hydrodynamic position is not an exclusive criterion, however, because many small pools occur in group (a) (Fig. 17).

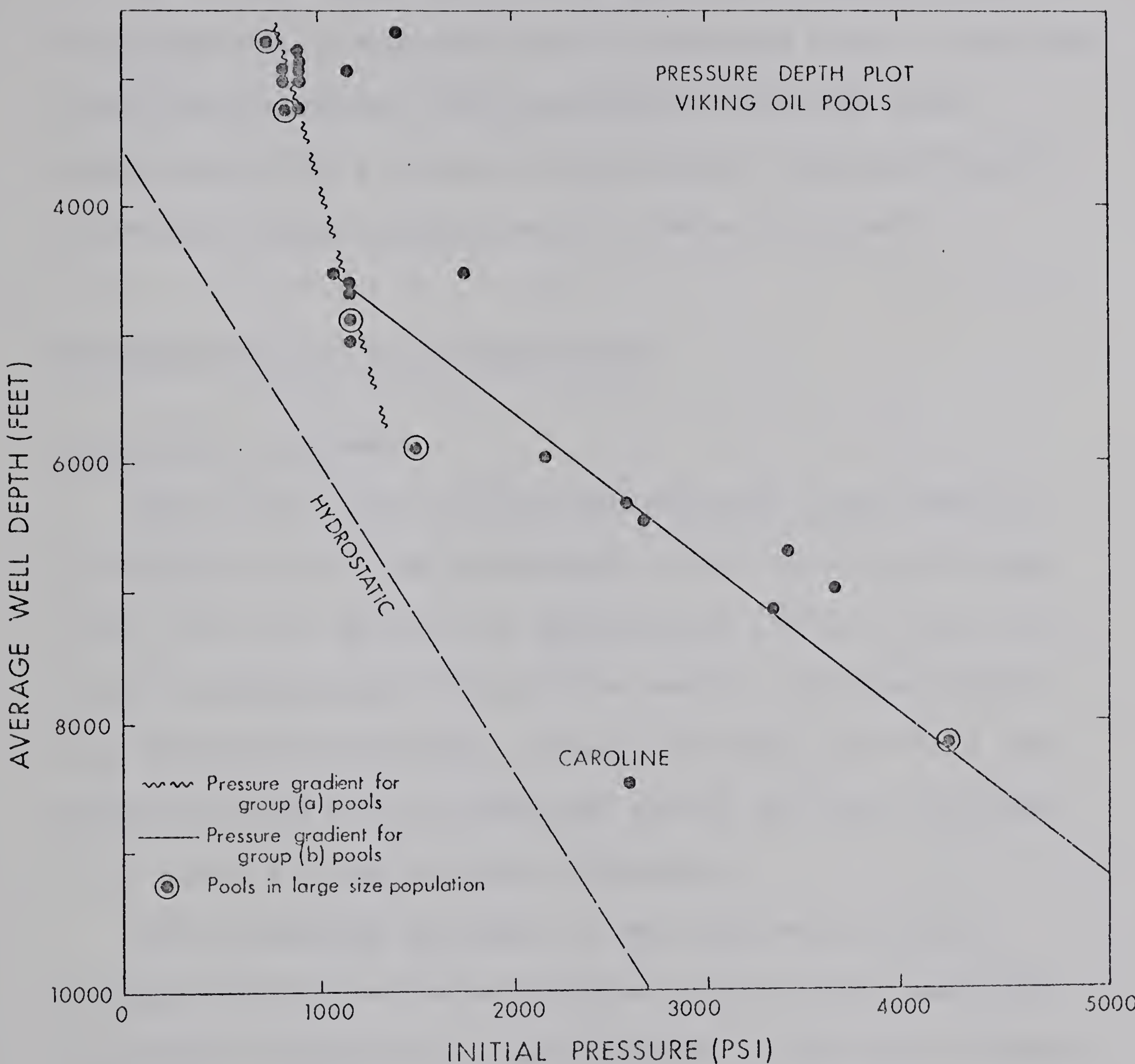

PRESSURE DEPTH PLOT
VIKING OIL POOLS
AVERAGE WELL DEPTH (FEET)
4000
6000
8000
10000
0
1000
2000
3000
4000
5000
INITIAL PRESSURE (PSI)
HYDROSTATIC
CAROLINE
Pressure gradient for group (a) pools
Pressure gradient for group (b) pools
Pools in large size population

FIGURE 17

Conclusion

From all lines of evidence, it seems that the hydrodynamic flow pattern is an important overall controlling factor in providing conditions suitable for the accumulation of the large (size population 2) Viking oil pools (Fig. 16), but a good development of the main Viking sandstone unit is a prime requirement.

Wabiskaw (Glauconitic) Gas Pools Study

Statistical Treatment

When Q-mode factor analyses were performed on gas pools in the Wabiskaw Member (and equivalents), it was found that the very large size of the Marten Hills Wabiskaw pool (772×10^9 cubic feet of gas in place) unduly distorted the results, and it was omitted from subsequent calculations. However, it would plot with a heavy weighting on any factor to which the size of the pool contributed (e.g. factor 3 in the following discussion).

For the Wabiskaw gas pools, it was found that a 3-factor varimax solution provided what appeared to be the most meaningful grouping of the pools, and accounted for 94% of the total variance. The percentage of the total variance accounted for by each varimax factor is

Factor 1: 57%

Factor 2: 24%

Factor 3: 13%

Fig. 18 is a crossplot of factor 1 against factor 3 for that solution, and as was the case for Viking oil pools (Fig. 14), there is a cluster of pools with high values for factor 1 and low values for factor 3. There is also a division of the non-clustered pools into those with high values for factor 3 and those with low readings for factor 3. The pools with low values for factor 1 and high values for factor 3 are the large pools belonging to population 2 in size frequency analysis.

Again, a minimum number of the most common variables (measurements) was used so that all pools could be included in the analysis, and the variables are listed below and are plotted on Fig. 19.

1. Pool plan area
2. Gas reserves
3. Average gas zone thickness
4. Regional dip
5. Pay zone top elevation
6. Porosity
7. Water saturation

The use of the "closed" variables, porosity and water saturation was discussed on p. 80. The comparison between Fig. 19 and Fig. 15 is evident insofar as factor 1 is controlled by the elevation of the pool and the porosity of the reservoir, and factor 3 is controlled by the area of the pool and gas reserves in

Q-MODE FACTOR ANALYSIS
WABISKAW MEMBER GAS POOLS
(4 FACTOR VARIMAX SOLUTION)

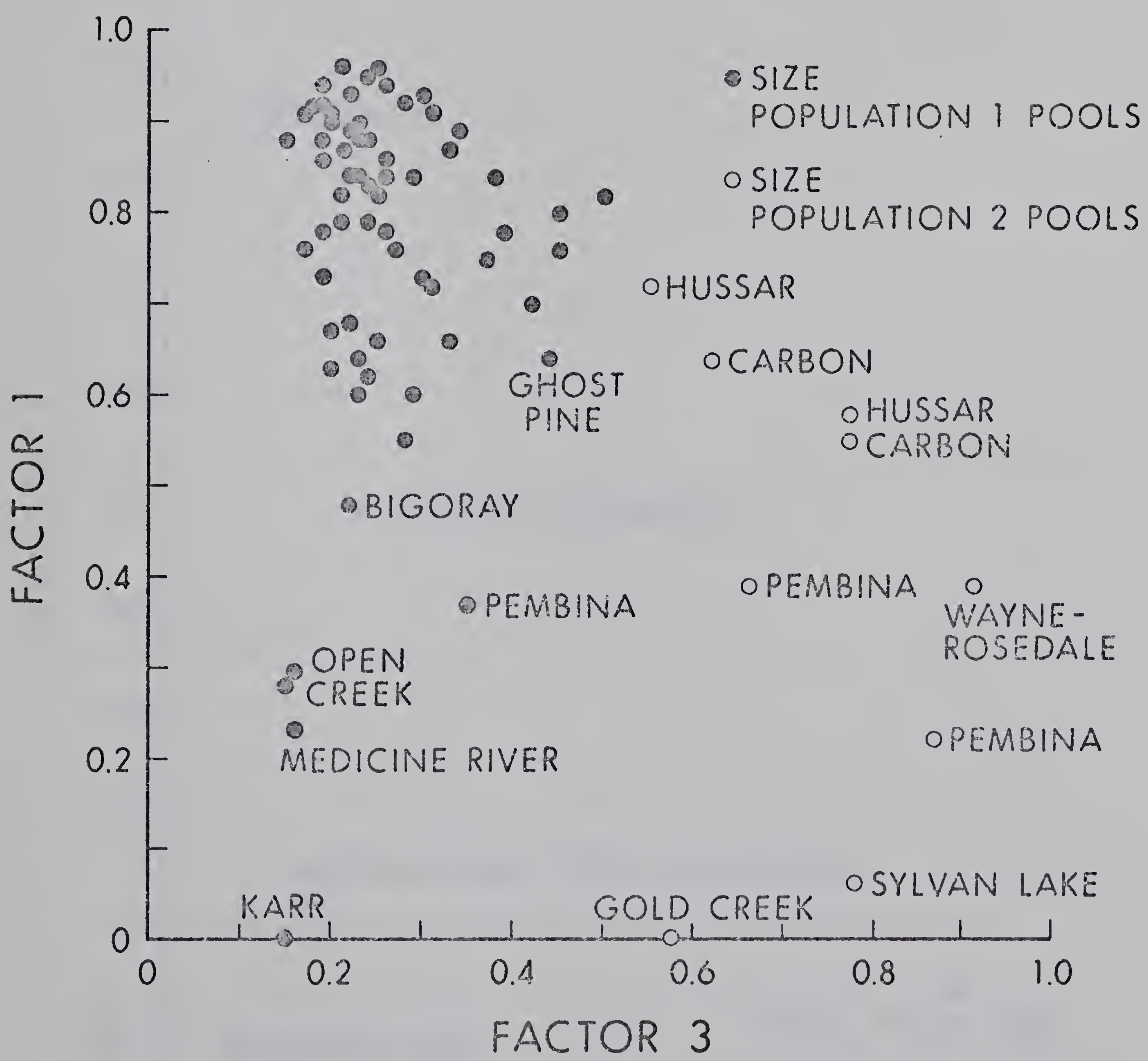


FIGURE 18

CONTRIBUTION OF VARIABLES TO FACTORS
(SCALED VARIMAX FACTOR SCORES)
FOR WABISKAW GAS POOLS FACTOR ANALYSIS

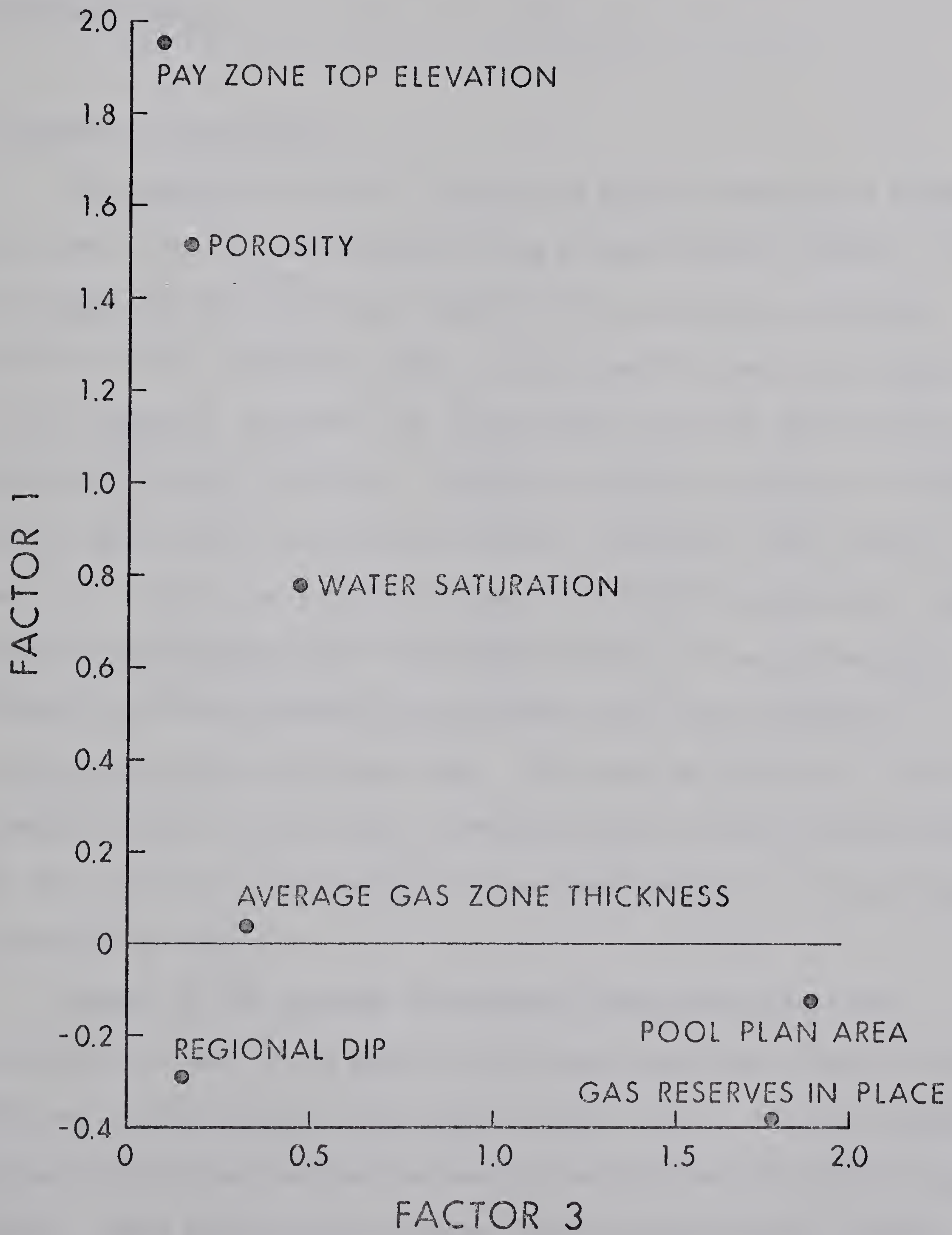


FIGURE 19

place (i.e. size). Therefore the pools in size population 2 (larger pools) are characterized by low elevations, low porosities, and relatively low water saturations. Table VI compares the values for these variables for the larger pools with the average for all Wabiskaw pools.

Geographic Significance

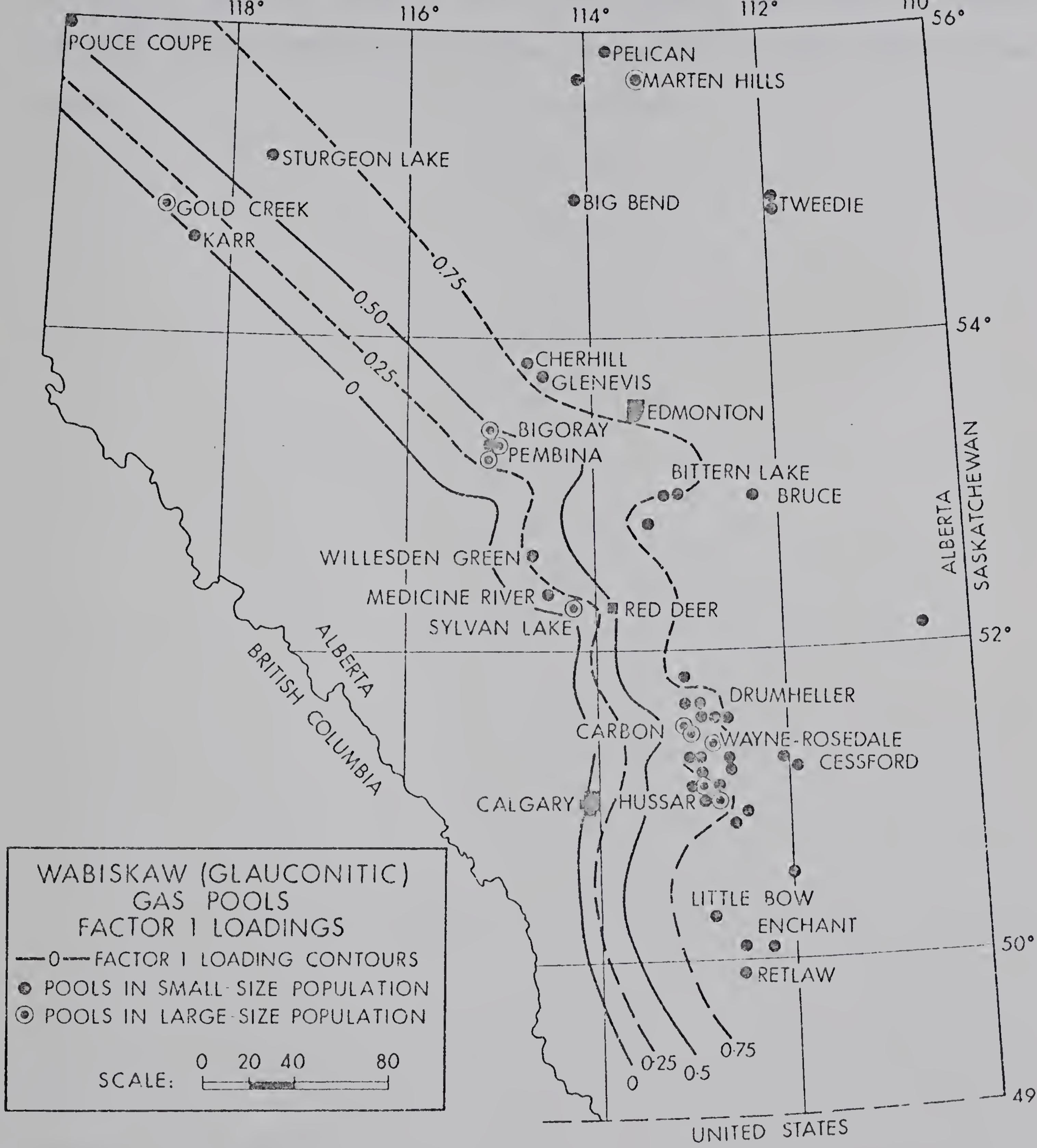
The loadings on factor 1 for all the Wabiskaw pools were plotted on a map (Fig. 20) and contoured using a broad contour interval. It is recognized that the factor loading values cannot be accurately defined in the geological sense, so only general trends were sought. In the graphical analysis, the larger pools (and some smaller ones) were seen to have low factor 1 loadings, and from the general contours on the map, these low loadings on factor 1 (and the larger pools) occur in a fairly well defined linear zone trending south-east. This zone is approximately the interpreted position of the southwestern shoreline of the transgressive Clearwater sea, which reached no further south than the Hussar area. There are no low factor 1 loadings south of Hussar, so the zone is projected west of Retlaw sub-parallel to the structural trend because of the contribution of a low pool top elevation to factor 1.

Because of the apparent correlation between low values for loadings on factor 1 and pools in the large population (population 2) defined by size analysis, the zone of lower factor 1 loadings appears to outline the most prospective area of exploration for Wabiskaw gas pools. Small pools within the zone should be examined for possible

TABLE VI

Wabiskaw (Glauconitic) and Equivalents Gas Pools

Pool Name	Elevation	Porosity	Water Saturation	Gas in Place B cf
Size Population 2 pools				
Carbon Glauconitic	-1995	.20	.35	50.5
Carbon Glauconitic other	-2025	.20	.35	106.4
Gold Creek Bluesky	-4630	.12	.20	63.3
Hussar Glauconitic A	-1680	.23	.25	75.6
Hussar Glauconitic N	-1544	.21	.30	107.0
Pembina Lobglauconitic A	-3214	.14	.40	170.0
Pembina Lobglauconitic B	-3041	.16	.30	92.8
Sylvan Lake Glauconitic A	-3794	.13	.30	207.8
Wayne-Rosedale Glauconitic A	-1660	.20	.30	172.0
Averages for all Wabiskaw Pools	-1737	.20	.33	14.0



118°
116°
114°
112°
110°
56°
54°
52°
50°
49°
POUCE COUPE
PELICAN
MARTEN HILLS
STURGEON LAKE
BIG BEND
TWEEDIE
GOLD CREEK
KARR
0.75
0.50
0.25
0
CHERHILL
GLENEVIS
EDMONTON
BIGORAY
PEMBINA
BITTERN LAKE
BRUCE
WILLESDEN GREEN
MEDICINE RIVER
SYLVAN LAKE
RED DEER
ALBERTA
SASKATCHEWAN
ALBERTA
BRITISH COLUMBIA
DRUMHELLER
CARBON
WAYNE-ROSEDALE
CESSFORD
CALGARY
HUSSAR
LITTLE BOW
ENCHANT
RETLAW
0
0·25
0·5
0·75
UNITED STATES
WABISKAW (GLAUCONITIC)
GAS POOLS
FACTOR 1 LOADINGS
—0—— FACTOR 1 LOADING CONTOURS
POOLS IN SMALL SIZE POPULATION
POOLS IN LARGE SIZE POPULATION
SCALE: 0 20 40 80

FIGURE 20

upgrading of gas reserves to the level of the population 2 pools and also any new Wabiskaw Member pools found in the zone are likely to have greater potential reserves than pools in other parts of the basin.

CHAPTER 4. ESTIMATION OF OIL AND GAS RESERVES FROM POOL PLAN AREA

Introduction

In the Alberta portion of the Western Canada Sedimentary Basin, petroleum exploration has reached a mature stage with close well control over most areas. Under these conditions, it is possible to define, in an area of interest, the largest "undrilled" area where no wells have tested a zone of potential hydrocarbon production. It would then be useful to be able to estimate the probable amount of oil or gas in place in the zone if all the maximum "undrilled" area contained oil or gas.

If the exploration of the area was continued, and a well was drilled and was not successful in locating oil or gas, then a new maximum area could be defined and the exploration economics recalculated. The procedure would be repeated until the maximum possible pool area, and therefore the maximum possible oil or gas reserve, was no longer economically attractive.

With a file such as CRETPET, it is possible to obtain an average conversion factor for pool plan area to oil or gas reserves in place for pools in a particular reservoir. The values for pool plan area and the gas or oil reserves in place for all pools in the zone of interest can be retrieved from the file, the values plotted on a scatter diagram, and subjected to regression analysis, with the plan area as the independent variable and the oil or gas reserves in place as the dependent variable.

Regression Analysis

As was the case for most of the graphical methods used in the study, natural logarithms of the pool plan area and reserves are used in calculations and constructing graphs. A common method of relating any two variables is to perform a simple linear regression analysis on the data, producing an "average" straight line through the data points. The regression line is of the form

$$Y = a + bX$$

where in this study

Y is the natural logarithm of in-place reserves,

X is the natural logarithm of pool plan area,

a is the intercept of the regression line on the Y axis when $X = 0$, and

b is the slope of the regression line.

For prediction of in-place reserves for a given plan area, the equation can be solved for given values of X (log plan area). Alternatively, the actual scatter diagram and regression line can be used by entering the required area on the abscissa, locating the equivalent point on the least-squares regression line, and reading off the value of reserves in place from the ordinate.

Reliability of the Estimate

The degree of linear correlation between the two variables is measured by the product-moment correlation coefficient r_{XY}, where

$$R_{XY} = \frac{\text{covariance }(X, Y)}{\sigma_X \cdot \sigma_Y}\text{, and}$$

σ_X is the standard deviation of the independent variable, and

σ_Y is the standard deviation of the dependent variable.

Values for the correlation coefficient (r_{XY}) range from +1 (complete positive correlation), through 0 (no correlation), to -1 (complete negative correlation). The value of R_{XY} provides an indication of the reliability of predicting the dependent variable from the independent variable using the straight line model.

Another measure of the reliability of the predicted value is the standard error of the estimate (S.E. est.) which is sensitive to the scatter of points about the regression line and to the number of data points used.

$$\text{S.E. est} = \sum_{1}^{m} \frac{(Y_{observed} - Y_{predicted})^2}{m - 2}$$

where m is the number of observations, and

$Y_{predicted}$ is the value of the dependent variable (reserves) predicted from the regression equation, and

$Y_{observed}$ is the value of the dependent variable (reserves) observed in the sample studied.

If both the plan area and oil or gas reserves are lognormally distributed, then for a particular value of plan area (X_1), the range of reserves values given by $[(Y_1 = a + bX) + \text{S.E.}_{est}]$ to $[Y_1 - \text{S.E.}_{est}]$ provides a 68% probability of a correct prediction. This method is an averaging technique applied to the whole range of values and as such is relatively imprecise.

A more comprehensive method involves the calculation of confidence limits at particular levels of significance (e.g. 95%, 90%) for a series of values of the independent variable, X, using the Student's t-distribution (Krumbein and Graybill, 1965, p. 229). Lines representing particular confidence limits can then be plotted on the scatter diagram and rapid visual evaluations can be made. Calculations using the Student's t-distribution, however, assume a normal distribution for both X and Y and it was felt that for the variables used (plan area and reserves in place), the distributions are not well enough defined to make the more detailed calculations meaningful.

Geologic Factors Affecting the Estimate

The reservoir parameters relating the plan area of a pool to its oil or gas reserves in place include:

1. Thickness of oil or gas zone,
2. Porosity of the reservoir rock,
3. Relative gas, oil and water saturation,
4. Pressure in the pool (gas reserves).

Relative frequency histograms for these parameters are plotted in Appendix IV , and as may be seen, the frequency distributions do not resemble the theoretical normal frequency distribution nor do the parameters tend to have only one value. Obviously, relationships between plan area and oil and gas reserves are complex, and their representation by a linear equation is only approximate. The range of values of reserves predicted by the linear regression equation from

any particular value of plan area has an unknown frequency distribution, and thus measures such as the standard error of the estimate have an undetermined quantitative significance.

Scatter Diagrams

In a general sense, the scatter plots of reserves against area reflect the combined effect of variations in all the variables (listed previously, p.100) which connect plan area and estimated reserves. For example, Ellerslie (Basal Quartz) pools (Figs. 21 and 22) exhibit low correlation coefficients (r_{XY}) between plan area and reserves (0.62 for oil reserves and 0.66 for gas) primarily because of the wide variation in thickness of the oil and gas zones (Appendix IV e, f) and porosity values (Appendix IV c). On the other hand, Cardium oil pools (Fig. 21) have a correlation coefficient of 0.94 indicating that reliable predictions of oil reserves can be made from a knowledge of the plan area of a pool.

The scatter diagrams also throw light on some of the anomalous size frequency distributions discussed earlier, in particular for the Viking oil pools and Wabiskaw (Glauconitic) gas pools. The plot for Viking oil pools (Fig. 21) shows no distinction between the population of large pools (population 2) and other pools. The factors responsible for the two populations apparently are not related to the calculation of reserves from area (thickness, porosity, etc.). The two populations appear to be present in the pool plan area, presumably caused by differences in the environment of deposition. The plot for Wabiskaw

SCATTER PLOTS AND REGRESSION ANALYSES
(OIL RESERVES vs AREA)
FOR MAJOR OIL RESERVOIRS
(Note: Each plotted point may represent more than 1 pool)

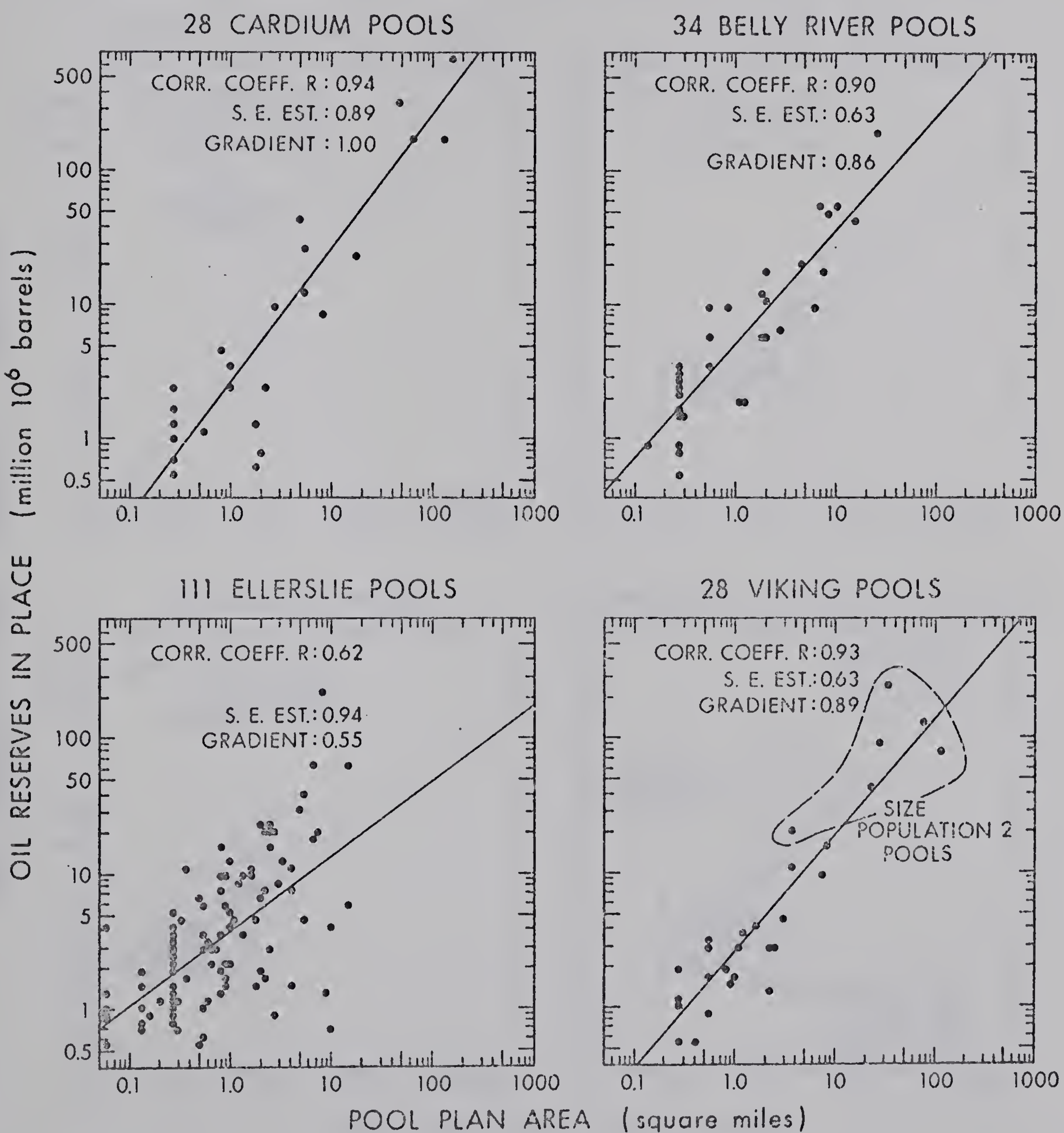


FIGURE 21

SCATTER PLOTS AND REGRESSION ANALYSES
(GAS RESERVES vs AREA)
FOR MAJOR GAS RESERVOIRS
(Note: Each plotted point may represent more than 1 pool)

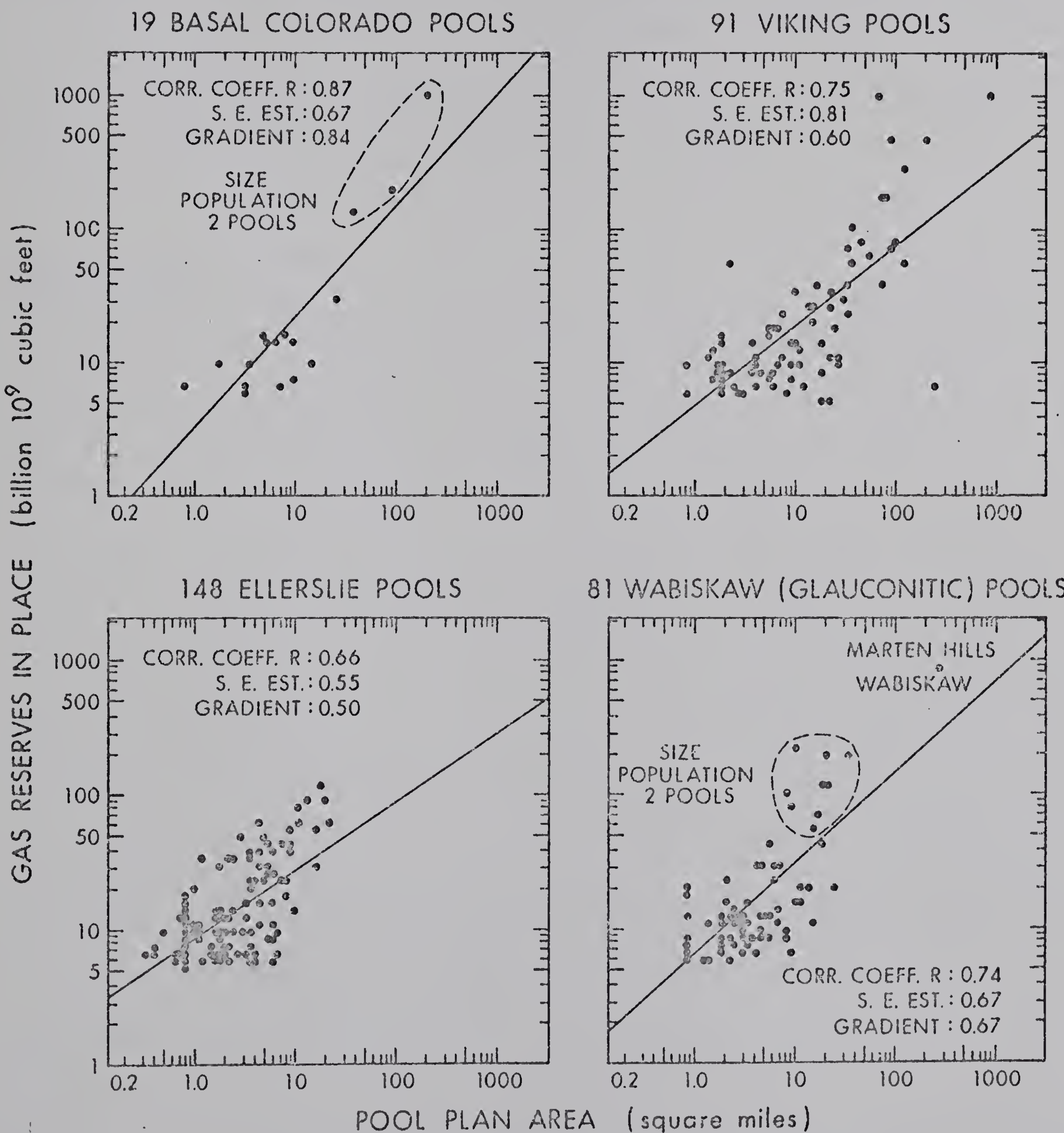


FIGURE 22

(Glauconitic) gas pools (Fig. 22) however, shows the group of large pools (population 2) with gas reserves higher than predicted by the regression line. It was suggested from the factor analysis of the pools that differences in porosity and elevation (and thereby pressure) were the causes of the anomalously large pools.

CHAPTER 5. WEIGHTED TREND FREQUENCY ANALYSES

Burk and Ediger (1966), in an earlier preliminary study, produced diagrams showing the preferred orientation directions of oil and gas pools occurring in major stratigraphic intervals in the Western Canada Sedimentary Basin. The data available in this study made it possible to carry out a more detailed investigation of preferred trends of Cretaceous oil and gas pools in Alberta.

Calculation

A major aim of the investigation was to illustrate graphically the preferred trends of oil and gas occurrences in the major reservoir units. It was felt, however, that merely counting the pools having particular trends was not satisfactory and a weighting procedure was adopted. A computer program was written which summed the reserves of oil and gas occurring in pools with major axis trends in each 5° sector from 0° to 180° (1° to 5°, 6° to 10°, ..., 176° to 180°), thus producing 36 trend-related values for oil or gas reserves. Because of the wide range of values obtained and the difficulty of representing that range on a diagram with an arithmetic scale, natural logarithms of the values were used in plotting the results on Figs. 23 to 27. The lines in the figures are drawn through the centres of each 5° sector.

Fig. 27, the overall summary for major reservoir units was prepared by converting gas reserves to the British Thermal Unit (B.T.U.) equivalent volume of oil using the conversion formula

5045 cubic feet of gas ≡ 1 barrel of oil

(British Petroleum Company Limited, 1970)

and adding them to the oil reserves for each 5° sector.

Diagrams for Major Oil Reservoirs

Many of the trend diagrams for the oil reservoirs show an expected preferred orientation in a NW-SE direction parallel to the present structural strike of the basin (Figs. 23 and 24). The influence of depositional strike of the reservoirs, however, is noticeable in a number of instances. Pools in the marine Cardium and Viking Formations (Fig. 23) are essentially unidirecitonal, parallel to the ancient shorelines. Mixed marine and non-marine deposits such as the Wabiskaw Member (Fig. 24) and Belly River Formation (Fig. 23) contain pods which have two preferred trends, one parallel to the assumed shoreline (NW-SE) and one perpendicular to the shoreline (NE-SW) corresponding to marine and non-marine deposits respectively. Oil occurrences in the continental sandstones of the Ellerslie Member (Fig. 24) appear to trend in all directions (except possibly East-West) reflecting the great variation in the alignment of these channel sands. The Basal Mannville (Fig. 24) in southern Alberta, in contrast, contains pools with the preferred trend directions of 10° to 50° and 310° to 340°, and these directions may be related to the structural influence of the Sweetgrass Arch.

Except as noted for the Basal Mannville pools in southern Alberta, the patterns shown by the trend frequency diagrams suggest that there has been no major realignment of the oil accumulations due to structural or hydrodynamic processes.

WEIGHTED TREND FREQUENCY DIAGRAMS FOR MAJOR OIL RESERVOIRS - I

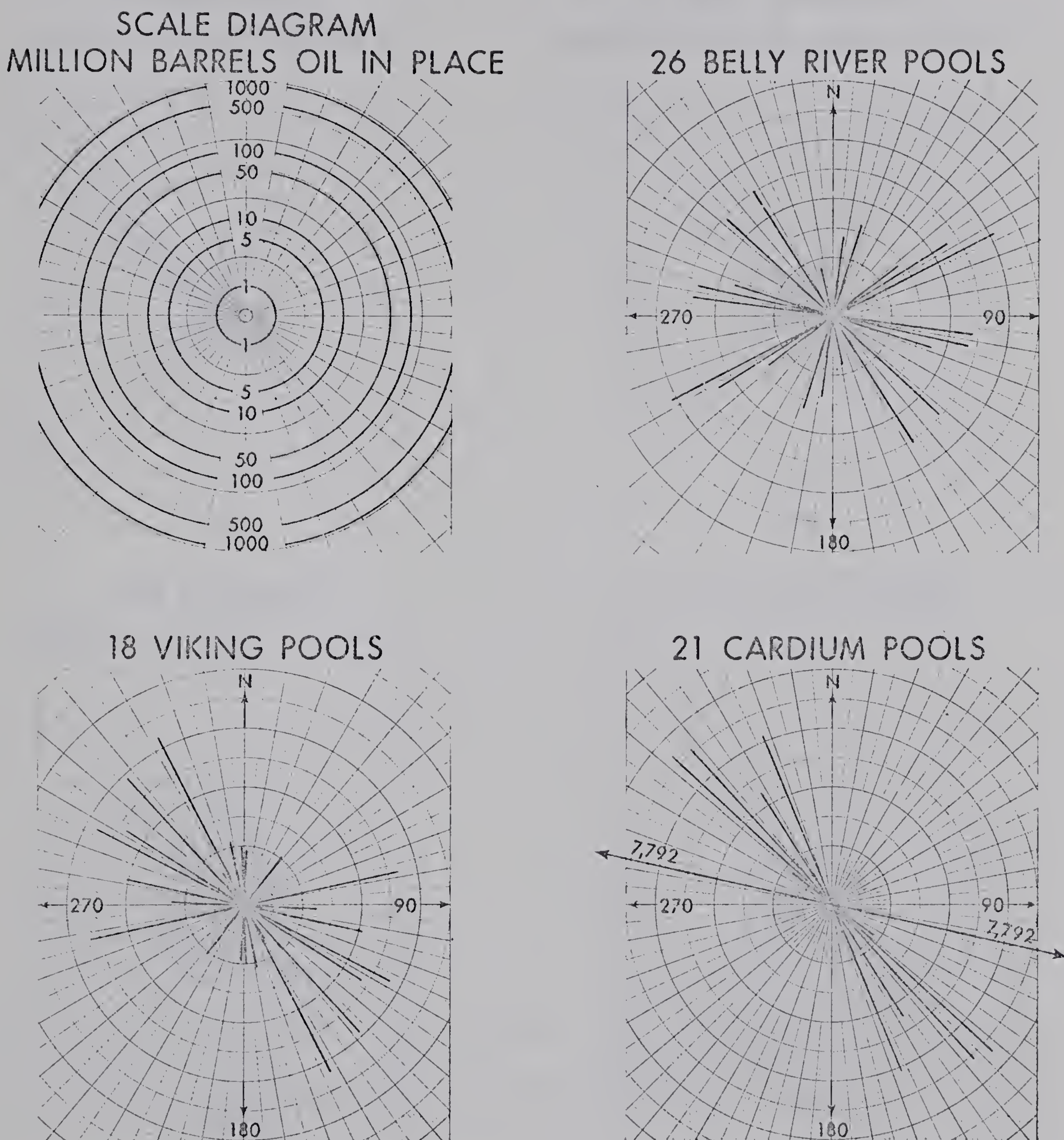


FIGURE 23

WEIGHTED TREND FREQUENCY DIAGRAMS FOR MAJOR OIL RESERVOIRS - II

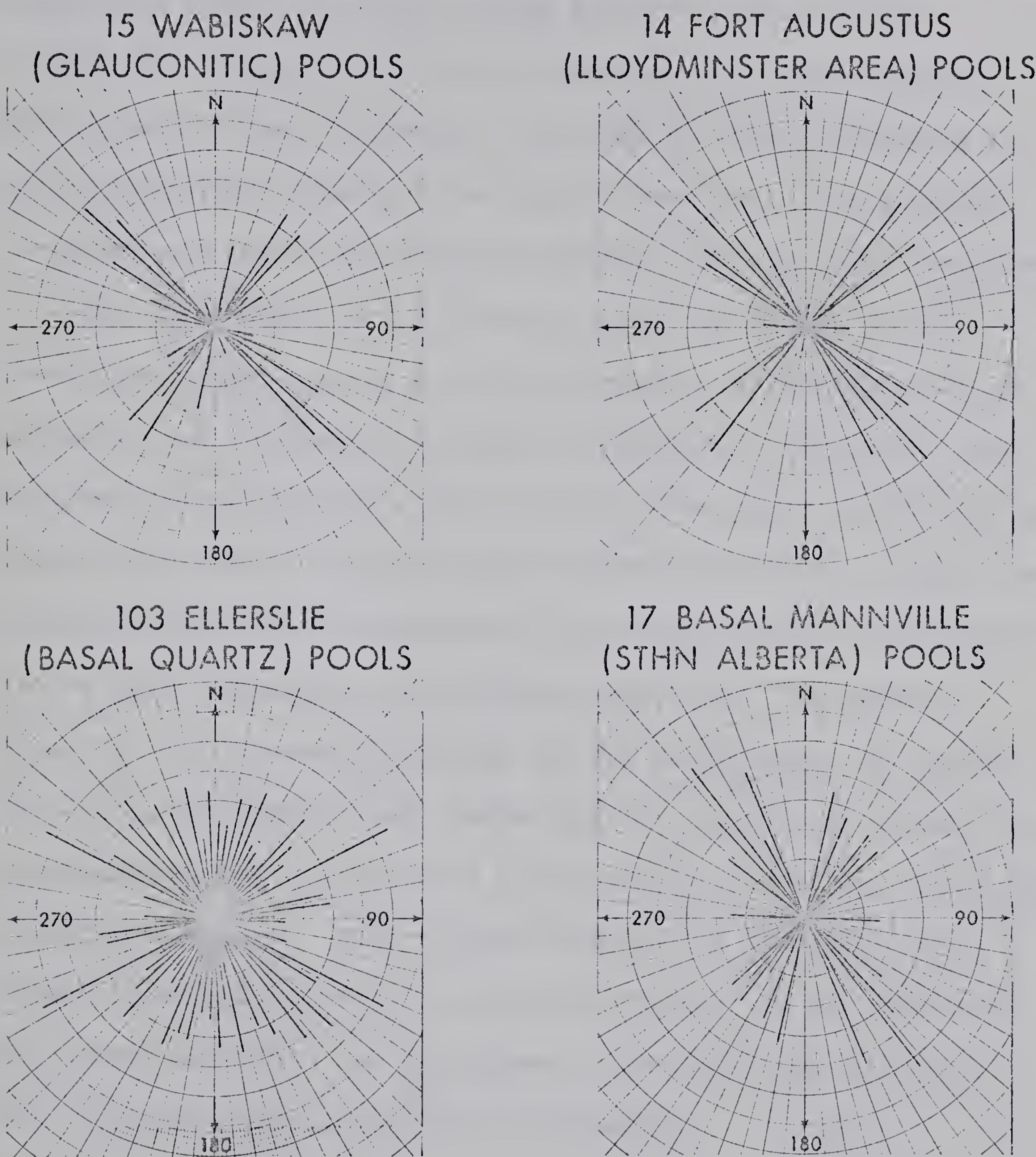


FIGURE 24

Diagrams for Major Gas Reservoirs

The analyses are dominated by a small number of very large gas pools with trend directions ranging from 60° (Medicine Hat), through 80° (Provost Viking) to 130° (Marten Hills Wabiskaw) and 150° (Cessford Basal Colorado). The range of trend directions for gas accumulations appears to be broader than for oil accumulations although most pools still show a preference for the NW-SE direction.

Gas occurrences in the Ellerslie (Fig. 26) trend in all directions except exactly E-W, again probably reflecting the broad spread in the alignments of channel sandstones in this unit. Only for such reservoirs as the Basal Colorado (Fig. 26), Cardium and Bow Island (Fig. 25) can unidirectional trends be defined, although some accumulations trend perpendicular to the main direction particularly in the Basal Colorado and Bow Island reservoirs. The greater diversity in preferred directions for gas accumulations as opposed to oil may be explained by the greater mobility of gas and its ability to migrate to and accumulate in a more diverse set of reservoirs than is possible for oil. Also gas can displace oil from reservoirs readily, and the present oil accumulations occur in the reservoir only where structural and hydrodynamic conditions are favourable, i.e. the most stable subsurface environments.

WEIGHTED TREND FREQUENCY DIAGRAMS FOR MAJOR GAS RESERVOIRS - I

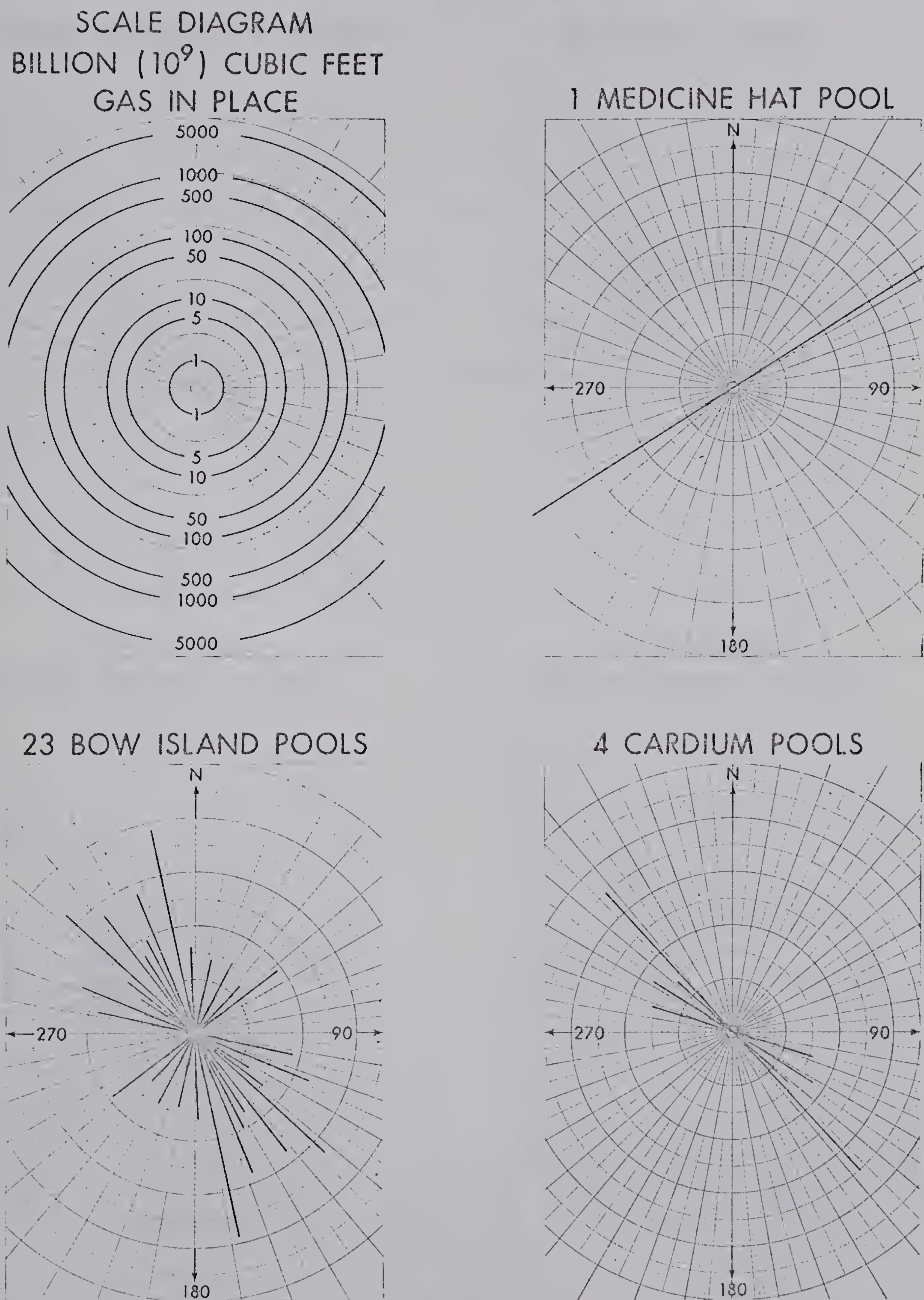


FIGURE 25

WEIGHTED TREND FREQUENCY DIAGRAMS FOR MAJOR GAS RESERVOIRS - II

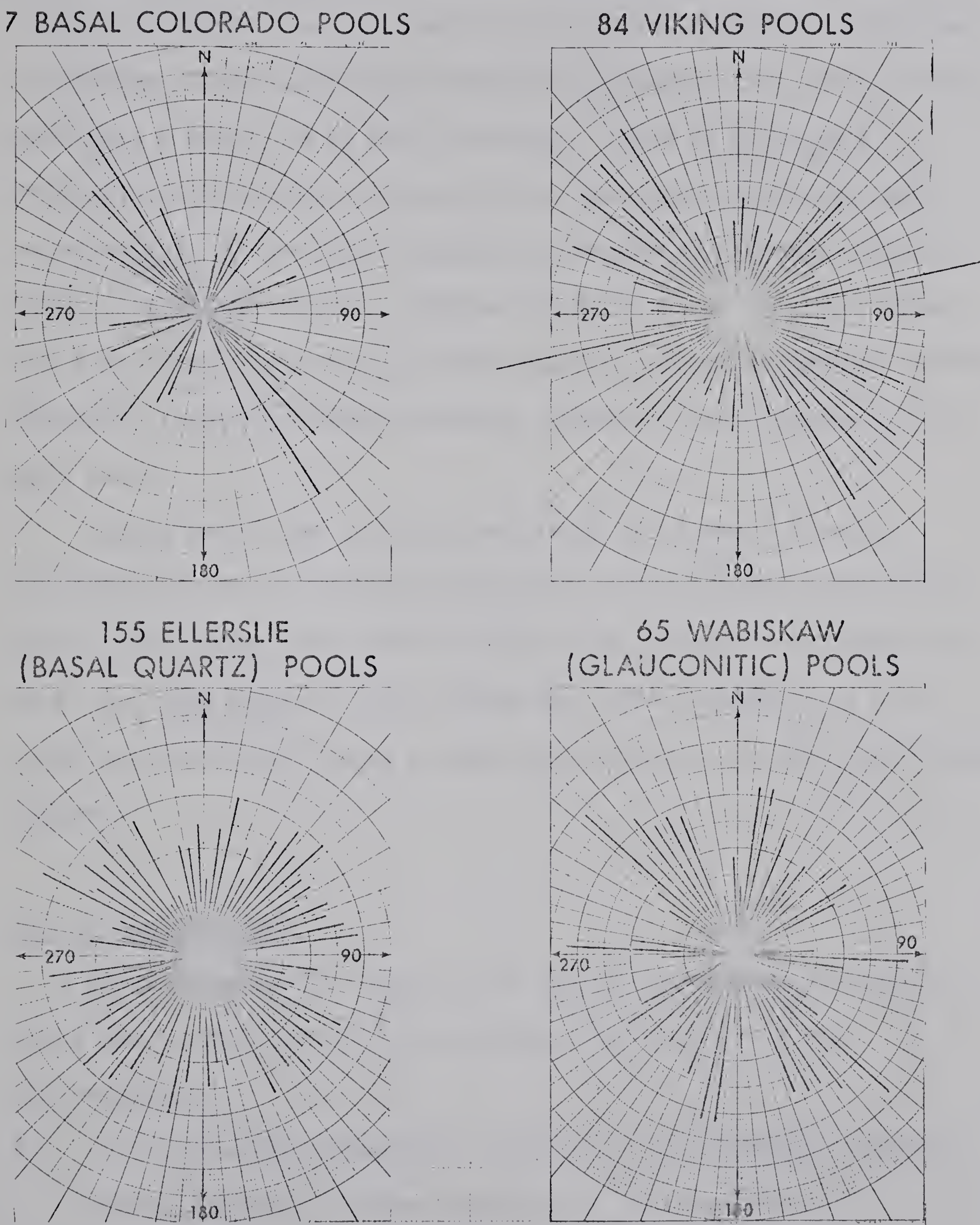


FIGURE 26

Diagram for Combined Oil and Gas Pools

When oil and gas reserves are combined as on Fig. 27, a range of patterns appears. Pools in the Ellerslie Member have trend directions almost uniformly distributed throughout the 180° of strike, with only a minor low at 90° (East-West). This is probably a reflection of the mode of deposition of the member as fluvial and related sands in erosional channels on the maturely-eroded Paleozoic surface (Williams, 1963). Wabiskaw and Belly River reservoirs show two almost equal directions, reflecting the non-marine (NE-SW trending channels) and marine (NW-SE trending shoreline sands) origin of the sand bodies.

Viking pools show a strong preference for a NW-SE trend as exhibited by the oil and gas occurrences in the western part of the basin, but a minor trend (40° to 80°) in the Provost area appears to be a localized feature in the Viking sea. The Cardium pools are truly unidirectional having a common depositional and post-depositional history.

Use of the Diagrams

It is proposed that sets of oil and gas trend diagrams such as these can be used for two main purposes: (a) analytical and (b) predictive.

(a) In the previous discussion, features of the diagrams have been related primarily to the depositional environment of the reservoir rocks because most of the oil and gas occurs in stratigraphic traps. If trends appeared which could only be

WEIGHTED TREND FREQUENCY DIAGRAMS FOR MAJOR RESERVOIRS

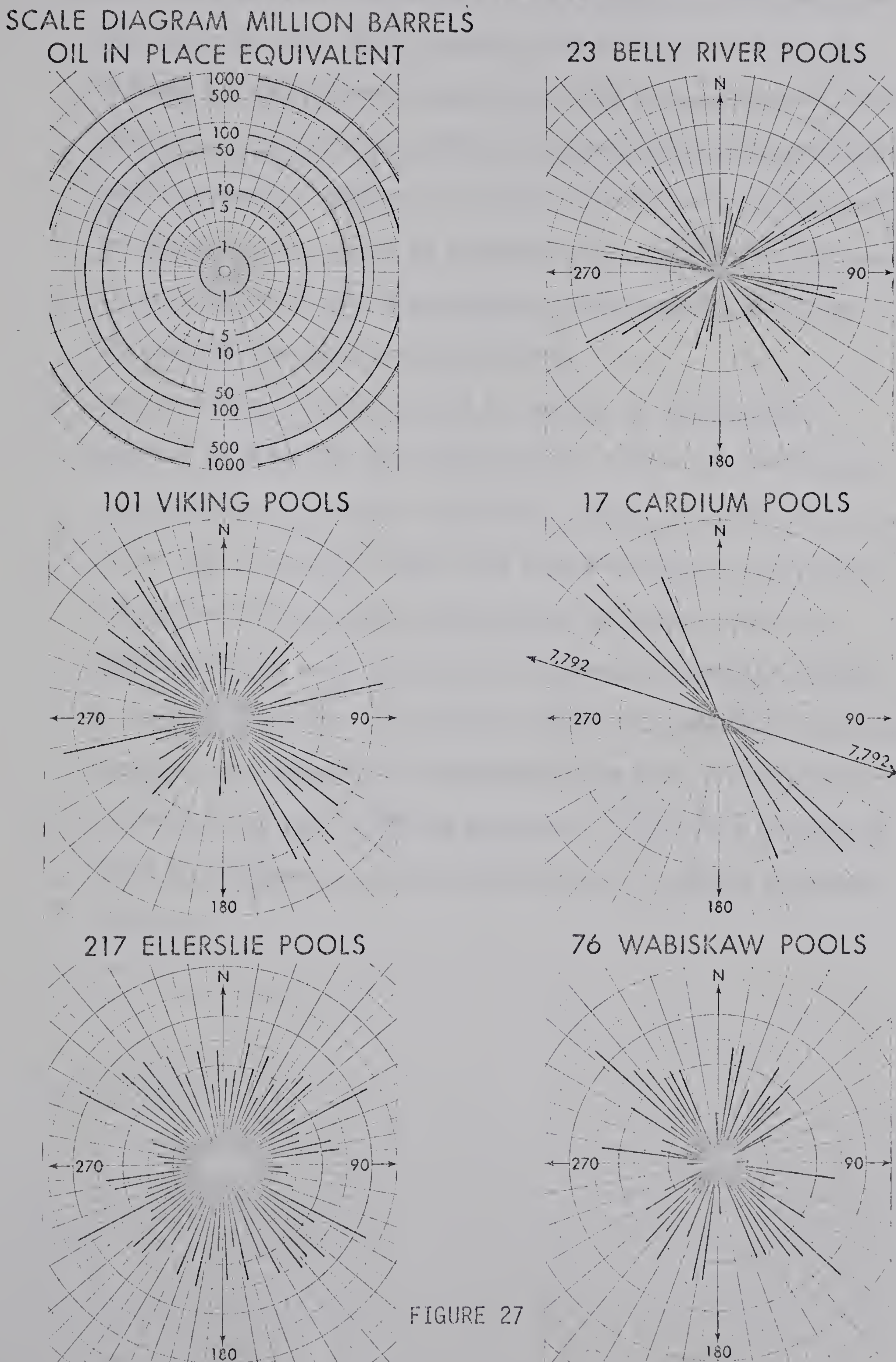


FIGURE 27

explained by local structural or hydrodynamic conditions then the diagrams could help determine the amount of oil and gas trapped by the different mechanisms, and give some idea of the relative effects of the different mechanisms on oil migration and entrapment. Removal of regional trends due to basin geometry, paleoslopes, etc. would be essential in a detailed analysis such as this, so that only the residual trend patterns would be assigned to the suggested mechanisms.

(b) Weighted trend diagrams could be used in an exploration program to determine the most prolific trends for oil or gas accumulation in specific reservoirs. Then, in terms of all the oil or gas previously found, the probabilities of discovering oil or gas accumulations with particular trends could be established and used as a part of the decision making process in land acquisition. In addition, such diagrams could supplement geological information in determining the most likely directions in which a new pool might be extended. Different alternatives could be proposed, and the probabilities of success calculated for each.

CHAPTER 6. PRESSURE - DEPTH RELATIONSHIPS IN MAJOR RESERVOIRS

The major component of fluid pressure in rocks in the subsurface is that exerted by the weight of the column of water filling the pore spaces of the overlying rocks, i.e. hydrostatic pressure (Levorsen, 1967). Fluid pressure gradients in excess of hydrostatic gradients are caused by phenomena such as differing fluid potentials, compaction, osmosis, and temperature gradients. Examination of the pressure gradients in a basin can help define reservoirs that belong to different fluid flow systems, and thereby reveal some aspects of the geology of the reservoir, and preferred hydrocarbon migration paths.

The best method of studying pressure conditions in a reservoir is to prepare scatter diagrams of the reservoir pressure against depth. A reference hydrostatic pressure gradient can then be drawn on the plot, using a gradient calculated from the salinity of the formation water. Deviations from the hydrostatic gradient indicate that there is a potential for fluid flow in the system, from points of higher pressure to points of lower pressure, when all values have been normalized to the hydrostatic gradient.

Scatter Plots

Elevations at the top of the pay zone (oil or gas zone) for each pool and initial pressures recorded in the pools are included in the CRETPET file. Relationships between reservoir elevation and pressure were obtained by plotting a series of scatter diagrams of pay zone

top elevation against initial pressure, and fitting a least squares regression line through the points. Plots for the major reservoirs are shown in Figs. 28 and 29, and the correlation coefficient r_{XY} as defined on page 99, is recorded on each diagram.

Use of the elevation of the top of the pool in the diagrams produces slightly different results as compared with plots using the average drilled depth as the depth measure. A series of pressure-depth plots for pools in Devonian reservoirs in Alberta (Energy Resources Conservation Board, 1970) uses both drilled depths and elevations and the gradients of the best-fit lines through the plotted points are found to be very similar for both measures. For the scatter plots produced in this study, a least squares regression line was calculated and constructed and the gradient of the line was recorded. This regression line is a type of "average" pressure gradient for the pools in the particular reservoir. The best defined gradient is for the Gething and Cadomin pools (40 psi/100 feet) with a correlation coefficient of 0.94, and this gradient is similar to the hydrostatic gradient calculated for typical formation waters from the Gething and Cadomin Formations. Most of the "average" gradients in Figs. 28 and 29 are approximately hydrostatic, but obvious exceptions include gas pools in the Basal Colorado sand (14 psi/100 feet), and oil pools in the Cardium (61 psi/100 feet) and Viking (71 psi/100 feet).

Features of the Scatter Plots

The anomalous gradient for gas pools in the Basal Colorado sand is calculated for only a small number of pools over a restricted pressure and depth range, so little significance can be attached to the very low gradient. As discussed in Chapter 3, page 87, and Fig. 17, the Viking oil pools have two distinct gradients, one less than hydrostatic and one greater than hydrostatic, because of the anomalous fluid potential low in the Gilby-Bentley area. The high "average" gradient of 71 psi/100 feet (Fig. 29) simply indicates that anomalous pressure conditions exist for the Viking oil pools.

Cardium oil pools occur in sandstone lenses within a thick shale section. The contained fluids were probably subjected to excess pressures due to compaction of the shales or Tertiary tectonism and these pressures have not yet equilibrated due to the inability of fluids to escape rapidly through continuous permeable aquifer systems. Numerous separate pressure systems have been delineated within the Cardium Formation, and consequently each group of sandstone lenses will retain its particular pressure characteristics. The "average" gradient of Fig. 29 is quantitatively meaningful when only one pressure system is involved, but for the Cardium it does indicate that the sandstone systems at depth have anomalously high pressures.

The crossplots also show interesting groupings among the Ellerslie oil and gas pools (Fig. 28) where three clusters of pools are found at different positions on the pressure-depth trend. These groups occur in bands roughly parallel to the structure contours of the basin (Fig. 30) and indicate the preferred pressure conditions

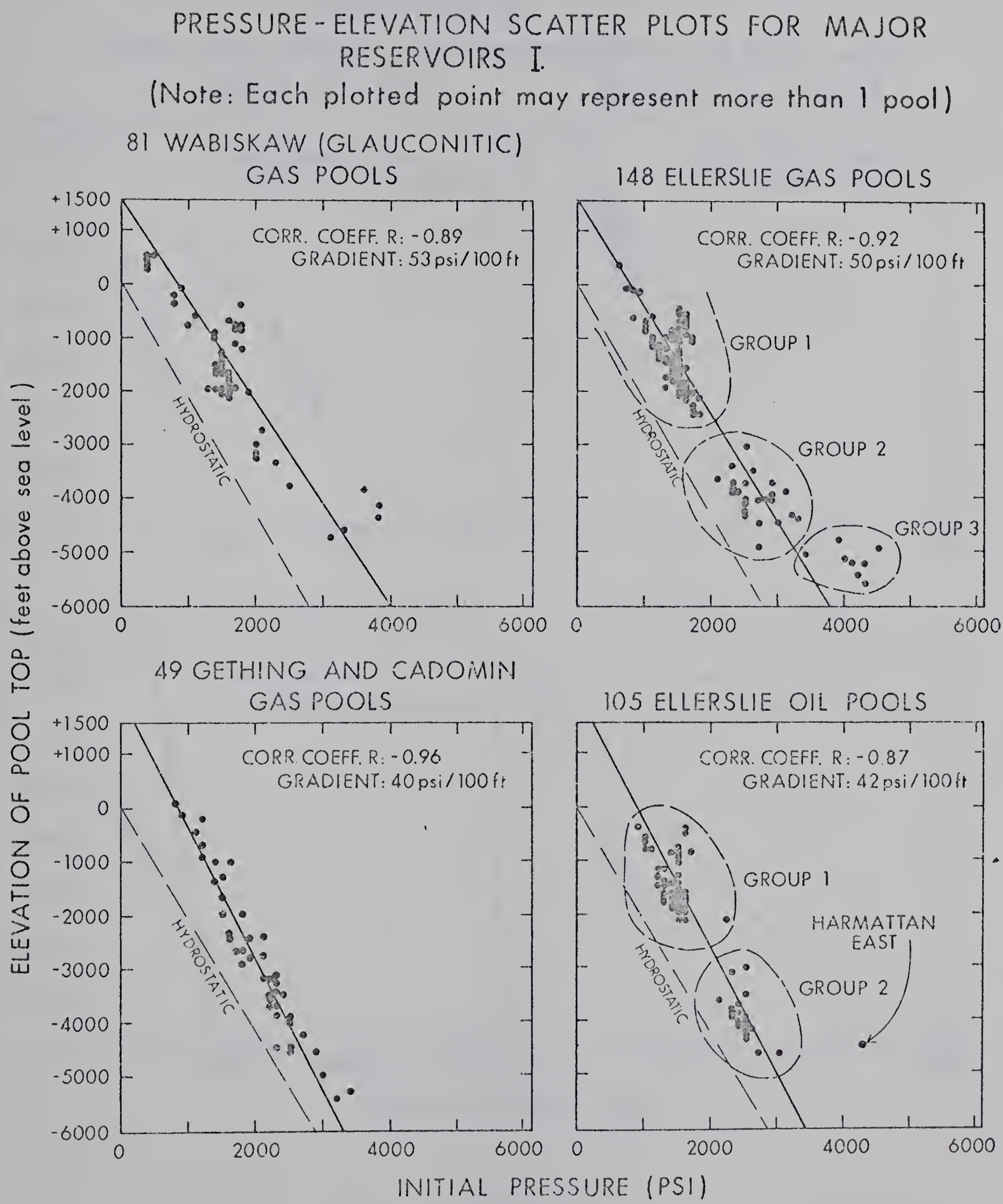

PRESSURE-ELEVATION SCATTER PLOTS FOR MAJOR RESERVOIRS I.
(Note: Each plotted point may represent more than 1 pool)
81 WABISKAW (GLAUCONITIC) GAS POOLS
CORR. COEFF. R: -0.89
GRADIENT: 53 psi/100 ft
HYDROSTATIC
148 ELLERSLIE GAS POOLS
CORR. COEFF. R: -0.92
GRADIENT: 50 psi/100 ft
GROUP 1
GROUP 2
GROUP 3
HYDROSTATIC
49 GETHING AND CADOMIN GAS POOLS
CORR. COEFF. R: -0.96
GRADIENT: 40 psi/100 ft
HYDROSTATIC
105 ELLERSLIE OIL POOLS
CORR. COEFF. R: -0.87
GRADIENT: 42 psi/100 ft
GROUP 1
HARMATTAN EAST
GROUP 2
HYDROSTATIC
ELEVATION OF POOL TOP (feet above sea level)
+1500
+1000
0
-1000
-2000
-3000
-4000
-5000
-6000
0
2000
4000
6000
INITIAL PRESSURE (PSI)

FIGURE 28

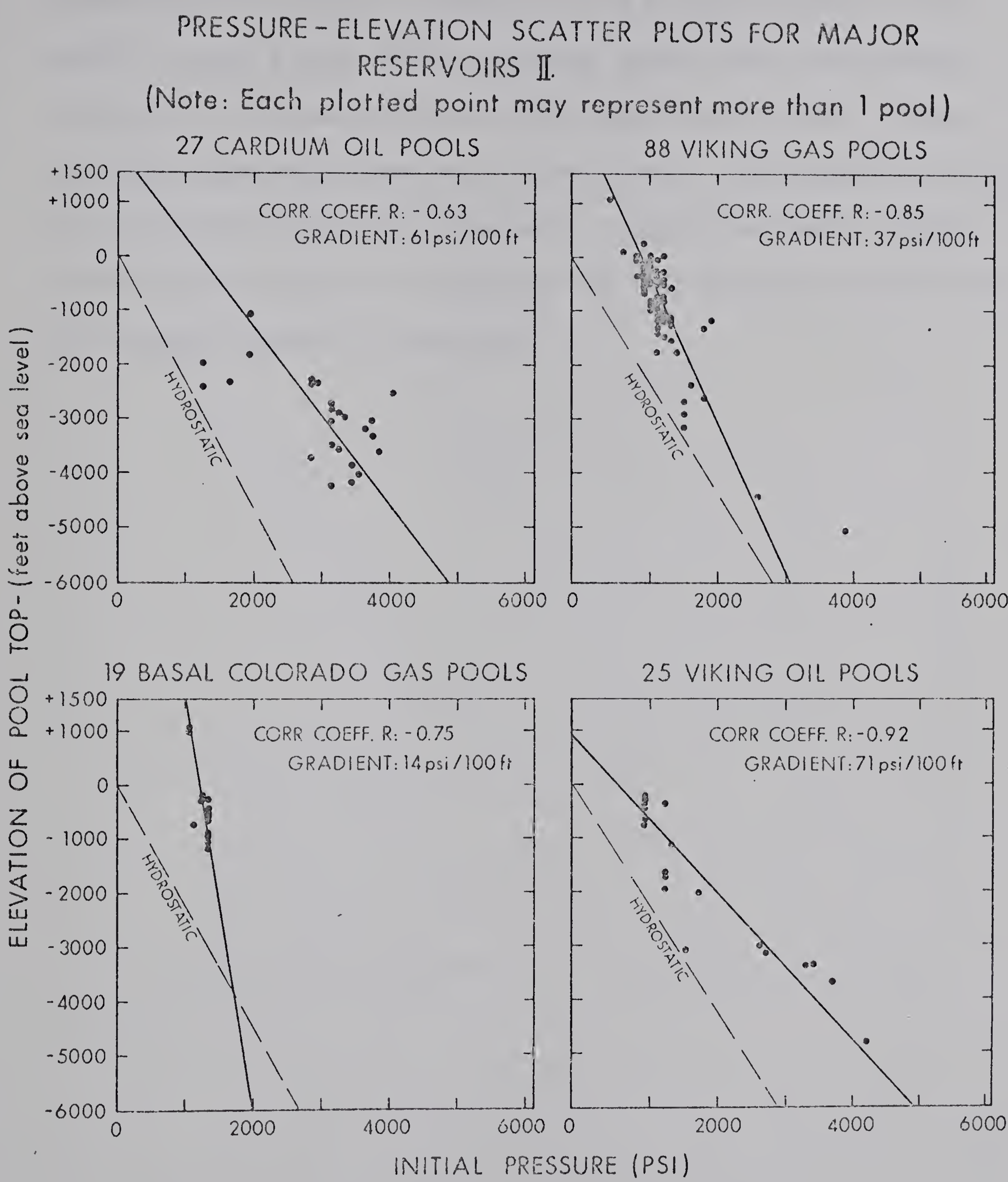

PRESSURE - ELEVATION SCATTER PLOTS FOR MAJOR RESERVOIRS II.
(Note: Each plotted point may represent more than 1 pool)
27 CARDIUM OIL POOLS
CORR. COEFF. R: - 0.63
GRADIENT: 61 psi/100 ft
HYDROSTATIC
88 VIKING GAS POOLS
CORR. COEFF. R: - 0.85
GRADIENT: 37 psi/100 ft
HYDROSTATIC
19 BASAL COLORADO GAS POOLS
CORR. COEFF. R: - 0.75
GRADIENT: 14 psi/100 ft
HYDROSTATIC
25 VIKING OIL POOLS
CORR. COEFF. R: -0.92
GRADIENT: 71 psi/100 ft
HYDROSTATIC
ELEVATION OF POOL TOP - (feet above sea level)
+1500
+1000
0
-1000
-2000
-3000
-4000
-5000
-6000
0
2000
4000
6000
INITIAL PRESSURE (PSI)

FIGURE 29

under which oil and gas accumulate in the Ellerslie Member. Gas pools in group 3 have initial pressures greater than the average trend and do not have any equivalents among the oil pools. These gas pools apparently occur west of the limit of recoverable Ellerslie oil and thereby define this boundary. The pressure-depth grouping of the Ellerslie pools is apparently not related to the size of the oil and gas reserves of the pools.

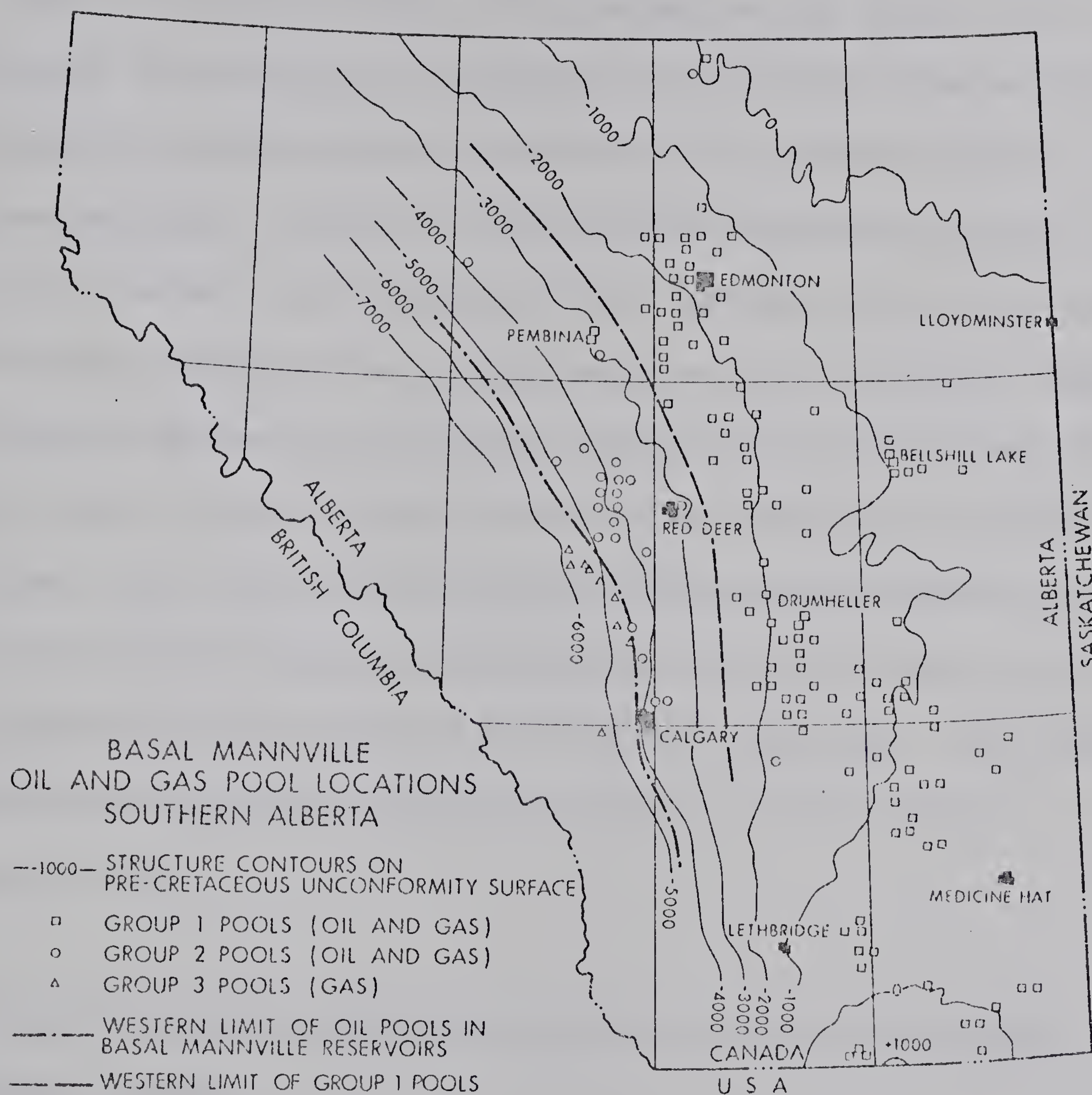

BASAL MANNVILLE
OIL AND GAS POOL LOCATIONS
SOUTHERN ALBERTA
-1000- STRUCTURE CONTOURS ON PRE-CRETACEOUS UNCONFORMITY SURFACE
GROUP 1 POOLS (OIL AND GAS)
GROUP 2 POOLS (OIL AND GAS)
GROUP 3 POOLS (GAS)
WESTERN LIMIT OF OIL POOLS IN BASAL MANNVILLE RESERVOIRS
WESTERN LIMIT OF GROUP 1 POOLS
EDMONTON
LLOYDMINSTER
PEMBINA
BELLSHILL LAKE
RED DEER
DRUMHELLER
CALGARY
MEDICINE HAT
LETHBRIDGE
ALBERTA
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
CANADA
U S A
-1000
-2000
-3000
-4000
-5000
-6000
-7000
+1000

FIGURE 30

CHAPTER 7. DIRECT CORRELATION OF OIL AND GAS POOLS WITH STRATIGRAPHY AND STRUCTURE

One of the initial aims of the project was to relate the occurrence of oil and gas in Cretaceous and Jurassic reservoirs to the detailed stratigraphy and structure of the Western Canada Sedimentary Basin. However, it has not been possible to pursue this aim to any extent, partly because of lack of time, and partly because sufficiently detailed stratigraphic maps were not available. Maps published by McCrossan and Glaister (1964) are too simplified, and on too small a scale to permit the detailed stratigraphic analysis required. This aspect of the work should be pursued further with the aim of determining what relationships exist, and their possible importance for exploration and for reserves estimation. The results of some preliminary work are shown in Figs. 31 and 32 and are discussed below.

Relation of Ellerslie (Basal Quartz) Pools to Mannville Channels in Central Alberta

Pre-Cretaceous erosion in central Alberta produced a mature landscape with northerly-flowing rivers occupying broad valleys which were separated by ridges underlain by more resistant formations (Williams, 1963). Basal sediments of the Mannville Group (mainly Ellerslie Member) were deposited preferentially in these valleys and their tributaries where clean thick sand sequences were built up on point bars and as channel fill. The channel deposits form attractive

reservoir rocks because of their generally high porosity and permeability, and have been the target of much oil and gas exploration. A plot of all the oil pools in the basal Mannville (Ellerslie equivalents) from the CRETPET file (Fig. 31) shows that oil occurrences are largely confined to the channels, as defined by Williams (1963) on the basis of the isopach of Base of Fish Scales to pre-Cretaceous unconformity surface. It is also apparent that oil occurs only in particular parts of the channels and that other factors, either structural or hydrodynamic, are operative in determining the positions of oil occurrence within the channels. Identification of these factors would provide a useful exploration tool.

Gas pools do not appear to be related to the channels as closely as the oil pools, probably reflecting the greater mobility of gas in migrating into structurally higher reservoirs, whether the reservoir is located in the channel or not.

Relation of Ellerslie (Basal Quartz) Pools to Filtered Structure Contours on the pre-Cretaceous Unconformity Surface

Robinson *et al*. (1969) applied a mathematical filtering process to various structure contour maps of the Western Canada Sedimentary Basin, in order to delimit intermediate scale structures in the basin. The resulting filtered map of the structure contours on the pre-Cretaceous unconformity surface theoretically identifies topographic features now present on that surface. This filtered map was overlain by plots of oil and gas pools found in the basal Cretaceous sandstones, and the relation between oil and gas occurrence and the filtered "structures" was calculated by summing the number of pools and the oil or gas reserves associated with each of three "structural" conditions - definite positive anomaly, neutral, and definite negative anomaly.

The results, listed in Table VII, indicate a correlation between negative "structural" anomalies and oil occurrence in the Basal Mannville, caused by the coincidence of oil pools and erosional lows on the unconformity surface. The positive anomalies apparently do not provide conditions suitable for the accumulation of oil. Gas, on the other hand, seems to favour the positive anomalies over negative anomalies, again probably because its greater buoyancy and migrational mobility enable the gas to move into "structurally" neutral or high positions. Most of the gas pools occur in "structurally" neutral positions.

To test the correlation between oil and gas occurrence and the types of anomalies on the filtered map, the map area covered by the

three types of anomalies was calculated (Table VII). The fractions of the total map area covered by each type were assumed to define the theoretical density function. If the frequencies of occurrence of oil or gas in the three classes are not significantly different from the theoretical densities (the null hypothesis), then there is no preferential accumulation of oil and gas on the filtered "structures". However, the "chi-square" test firmly rejects the null hypothesis and the geological reasoning, above, therefore is supported.

TABLE VII

RELATION OF OIL AND GAS POOLS TO STRUCTURE

ON PRE-CRETACEOUS UNCONFORMITY SURFACE

Residual Features on Filtered Structure Contour Maps

	Definitely + ve	Neutral	Definitely -ve
Fraction of Map area	.263	.561	.176
OIL POOLS			
No. of pools	30	51	40
Oil in place (barrels)	229.0×10^6	659×10^6	311×10^6
Expected oil in place (barrels			

$U = 64 > [\chi^2_{(2)} = 1.39]$ $\therefore$ Null hypothesis rejected

	Definitely + ve	Neutral	Definitely -ve
GAS POOLS			
No of pools	46	88	38
Gas in place (cu. ft.)	1028×10^9	1470×10^9	680×10^9
Expected gas in place (cu. ft.)			

$U = 110 > [\chi^2_{(2)} = 1.39]$ $\therefore$ Null hypothesis rejected

CHAPTER 8. SUMMARY AND CONCLUSIONS

Summary

The overall objectives of this study (p. 4) were

(i) to design a workable format for the computer storage and retrieval of geologic data on oil and gas pools,

(ii) to select and develop a file system most suited to this type of data manipulation,

(iii) to build a file on Cretaceous and Jurassic oil pools in Alberta, and

(iv) to analyze the data in the file and suggest possible applications.

Initially, relevant data on oil and gas pools were organized into six categories: identification and location, stratigraphic sequence, unconformity relationships, lithologic data, geometric data, and technical reservoir data. A generalized storage and retrieval system, SAFRAS, under development at University of Western Ontario, was chosen as most readily adaptible to the needs of a large, developing body of data such as would be collected for this project. Alterations to the structure of SAFRAS during the course of the study, ultimately produced a slightly different version of the system which was termed UASAFRAS.

The file of data collected, called the CRETPET file, was restricted to oil and gas pools in Cretaceous and Jurassic reservoir rocks in Alberta because of the large number of such pools, the

ready availability of information on them, and the relatively consistent geological features shown by the reservoir rocks. By considering only pools with in-place reserves of greater than 0.5×10^6 barrels of oil or 5.0×10^9 cubic feet of gas, the number of pools for which data were collected was kept to 1101. Many of the items of data which at first were thought to be desirable were found to be not easily obtainable as collection proceeded. Similarly some data were apparently not amenable to analysis, and therefore were of limited use. From experience gained in building and using the file, a list of data items considered necessary to describe an oil or gas pool and a suggested structure for computer-based files of this type were developed.

Initial analysis of the data collected dealt with the sizes of the pools (recorded as in-place reserves, plan area, and axial lengths), and these size measurements appear to be lognormally distributed. Although anomalies such as the probable overestimation of reserves in small pools were identified, cumulative frequency curves for pools in the major reservoirs were useful for estimating the probability of discovering new pools having specified quantities of in-place reserves, and thus could be valuable as exploration tools.

Two populations of pools (one large, one small) were distinguished from the size frequency distribution curves for Viking oil pools and Wabiskaw gas pools, and it is suggested that unknown factors operated to form the larger pools. One possible factor was suggested in the case of the Wabiskaw Member which could lead to the delineation of

areas where the geology was more favourable for the occurrence of large pools. The explanation for the bimodality in the sizes of Viking oil pools apparently is complex, but may be related to the depositional environments of the reservoir sandstones and to subsequent fluid movement patterns.

Much of the data analysis attempted to define the frequency of occurrence of measures such as reserves, area, and pool trend direction in the inventory of pools in CRETPET, and to establish relationships between pool measurements, particularly areas and oil or gas reserves. From the graphs produced, predictions can be made about the probable sizes, shapes, and trend directions of pools which may be found in any particular reservoir in the basin. Such predictions can be used to estimate the maximum probable reserves in reservoirs beneath a block of undrilled land, an initial step in land evaluation. If production is found, the probable direction of elongation of the accumulation can be determined from weighted trend frequency diagrams, thus aiding in the location of subsequent wells.

Pressure-elevation crossplots were prepared for pools in the major reservoirs and were found to be useful in considerations of fluid flow patterns, and the location of anomalously pressured reservoirs. From the crossplots, it was also possible to define a western limit for the occurrence of oil in reservoirs in the Lower Mannville Group.

A brief study of the relationship between oil and gas occurrence in Lower Mannville reservoirs and the location of channels

on the pre-Cretaceous unconformity surface confirmed that the hydrocarbon accumulations occur preferentially in the infilled channels. The locations of gas pools are less predictable than those of oil pools, probably because of the greater mobility of gas, but the preference for a channel location is still apparent. When pools in Lower Mannville reservoirs are located with respect to erosional "structural" anomalies on the unconformity surface, oil pools again exhibit a decided preference for "structurally" low positions, whereas gas pools occur in "structurally" low and neutral locations.

Conclusions and Recommendations

It has been shown that a computer-based file of data on the geologic features of oil and gas pools is practical, and that such a file can be used both as a tool for petroleum exploration and to evaluate the petroleum potential of an area. Although the CRETPET file included only the Cretaceous and Jurassic pools of Alberta, it was designed to accommodate data on petroleum occurrences in all types of reservoir rocks. A logical expansion of the file would be to incorporate data on oil and gas pools in the Mississippian and Devonian systems which comprise 60% of the petroleum reserves in Alberta. Also oil and gas occurrences in Manitoba, Saskatchewan, British Columbia, and the Northwest Territories should be included to provide a complete inventory for the Western Canada Sedimentary Basin.

The CRETPET file contains data extant to February, 1969, and provision should be made for revising the file possibly every 4-5 years. Major revisions are not likely to be required for each time but projections and predictions will be more accurate if the data are current.

The following data now present in CRETPET were not evaluated fully in this project:

(a) stratigraphic sequence data,

(b) unconformity data, and

(c) lithologic data

Testing of these data should attempt to find out whether the mnemonic codes or hierarchical numeric codes used for stratigraphic data are more suitable, and if the apparent connection between stratigraphy and lithology holds for each pool. Finally, a large quantity of lithologic data now in the file has not been exploited in any way, and their use could prove to be a very powerful tool in the characterization of existing oil and gas pools, and in the exploration for new accumulations.

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APPENDIX I

DATA SPECIFICATIONS — OIL AND GAS POOLS FILE

		FIELD WIDTH	DEC	DATA TYPE	% OF DATA COLL.
	*0101 IDENTIFICATION AND LOCATION				
01	INSTITUTION	004		A	100
02	REFERENCE-NUMBER	010	00	N	100
03	PROVINCE	004		A	100
04	AUTHORITY	020		X	100
05	FIELD-NAME	020		X	100
06	FIELD-CODE	003	00	N	100
07	POOL-NAME	020		X	100
08	FORMATION-CODE	003	00	N	100
09	POOL-CODE	003	00	N	100
10	AXIAL-LOCATION-LAT	004	05	N	100
11	AXIAL-LOCATION-LONG	005	05	N	100
12	AXIAL-LOCATION-LSD	002	00	N	100
13	AXIAL-LOCATION-SEC	002	00	N	100
14	AXIAL-LOCATION-RGE	002	00	N	100
16	AXIAL-LOCATION-MER	001	00	N	100
17	AXIAL-LOCATION-PRECISION	001	00	N	100
18	MAX-RESERVOIR-LOCN-LAT	004	05	N	100
19	MAX-RESERVOIR-LOCN-LONG	005	05	N	100
20	MAX-RESERVOIR-LOCN-LSD	002	00	N	100
21	MAX-RESERVOIR-LOCN-SEC	002	00	N	100
22	MAX-RESERVOIR-LOCN-TWP	003	00	N	100
23	MAX-RESERVOIR-LOCN-RGE	002	00	N	100
24	MAX-RESERVOIR-LOCN-MER	001	00	N	100
25	MAX-RESERVOIR-LOCN-PRECISION	001	00	N	100
26	POOL-TYPE	004		A	100
27	REGIONAL-TECTONIC-ELEMENT	020		X	100
28	RELATED-TO-UNCONFORMITY	003		A	100
29	REFERENCE-TEXT-ONE	025		X	
30	REFERENCE-TEXT-TWO	025		X	
31	REFERENCE-TEXT-THREE	025		X	

ALPHABETIC DATA ----- A
NUMERIC DATA -------- N
ALPHANUMERIC DATA --- X

		FIELD WIDTH	DEC	DATA TYPE	% OF DATA COLL. R	O	U
*0203	STRATIGRAPHIC CATA				R	O	U
01	STRAT-POSITION-OF-UNIT	001		A	98	94	68
02	STRAT-UNIT-GP-NAME	004		A	96	94	66
03	STRAT-UNIT-GP-MOD	001		X	96	92	58
04	STRAT-UNIT-GP-AGE	003	00	N	96	94	66
05	STRAT-UNIT-FM-NAME	004		A	58	24	38
06	STRAT-UNIT-FM-MOD	001		X	00	00	00
07	STRAT-UNIT-FM-AGE	003	00	N	58	24	38
08	STRAT-UNIT-MBR-NAME	004		A	06	00	06
09	STRAT-UNIT-MBR-MOD	001		X	00	00	00
10	STRAT-UNIT-MBR-AGE	003	00	N	06	00	06
11	STRAT-UNIT-INFORMAL-NAME	004		A	32	28	04
12	STRAT-UNIT-INFORMAL-MOD	001		X	04	00	00
13	STRAT-UNIT-INFORMAL-AGE	003	00	N	32	28	04
14	GENERAL-DEPOS-ENVIRONMENT	002	00	N	48	66	50
15	DETAILED-DEPOS-ENVIRONMENT	020		X	12	20	04

R - RESERVOIR UNIT   O - OVERLYING UNIT   U - UNDERLYING UNIT

	FIELD WIDTH	DEC	DATA TYPE	% OF DATA COLL.
*0301 UNCONFORMITY DATA				
01 UNCONFORMITY-TYPE	004		A	000
02 POOL-RELATION-TO-UNCONF	004		A	100
03 RELATED-UNCONF-RELIEF-FEATURE	004		A	002
04 VERTICAL-DISTANCE-FROM-UNCONF	003	00	N	023
05 UNIT-ABOVE-UNCONF-GP-NAME	004		A	100
06 UNIT-ABOVE-UNCONF-GP-MOD	001		X	100
07 UNIT-ABOVE-UNCONF-GP-AGE	003	00	N	100
08 UNIT-ABOVE-UNCONF-FM-NAME	004		A	055
09 UNIT-ABOVE-UNCONF-FM-MOD	001		X	000
10 UNIT-ABOVE-UNCONF-FM-AGE	003	00	N	055
11 UNIT-ABOVE-UNCONF-MBR-NAME	044		A	004
12 UNIT-ABOVE-UNCONF-MBR-MOD	001		X	000
13 UNIT-ABOVE-UNCONF-MBR-AGE	003	00	N	004
14 UNIT-ABOVE-UNCONF-INF-NAME	004		A	026
15 UNIT-ABOVE-UNCONF-INF-MOD	001		X	002
16 UNIT-ABOVE-UNCONF-INF-AGE	003	00	N	026
17 UNIT-BELOW-UNCONF-GP-NAME	004		A	075
18 UNIT-BELOW-UNCONF-GP-MOD	001		X	031
19 UNIT-BELOW-UNCONF-GP-AGE	003	00	N	075
20 UNIT-BELOW-UNCONF-FM-NAME	004		A	053
21 UNIT-BELOW-UNCONF-FM-MOD	001		X	000
22 UNIT-BELOW-UNCONF-FM-AGE	003	00	N	053
23 UNIT-BELOW-UNCONF-MBR-NAME	004		A	008
24 UNIT-BELOW-UNCONF-MBR-MOD	001		X	000
25 UNIT-BELOW-UNCONF-MBR-AGE	003	00	N	008
26 UNIT-BELOW-UNCONF-INF-NAME	004		A	000
27 UNIT-BELOW-UNCONF-INF-MOD	001		X	000
28 UNIT-BELOW-UNCONF-INF-AGE	003	00	N	000

% CALCULATED FOR THE 251 POOLS RELATED TO AN UNCONFORMITY

		FIELD WIDTH	DEC	DATA TYPE	% OF DATA COLL. 9	6
	*0409 LITHOLOGIC CATA					
01	ROCK-TYPE	004		A	41	62
02	PROPORTION-OF-LITHOLOGY	002	02	N	41	62
03	RELATICN-TC-POOL	001		A	41	62
04	STRATIGRAPHIC-UNIT-GRCUP	008		X	41	62
05	STRATIGRAPHIC-UNIT-FM	008		X	15	23
06	STRATIGRAPHIC-UNIT-MEMBER	008		X	02	03
07	STRATIGRAPHIC-UNIT-INFORMAL	008		X	04	06
08	COLOR	004		A	35	53
09	CRYSTALLINITY	004		A	40	60
10	UPPER-SIZE-LIMIT	004		A	19	29
11	MEDIAN-SIZE	004		A	32	48
12	LOWER-SIZE-LIMIT	004		A	17	26
13	CLAST-COMPOSITION-ONE	004		A	38	57
14	CLAST-CNE-PROPORTION	002	02	N	06	09
15	CLAST-COMPOSITICN-TWO	004		A	10	15
16	CLAST-TWO-PROPORTION	002	02	N	01	02
17	ACCESSORY-MIN-ONE	004		A	26	39
18	ACCESSORY-MIN-TWO	004		A	11	17
19	FOSSIL-TYPE-ONE	004		A	07	11
20	FOSSIL-TYPE-TWO	004		A	01	02
21	FOSSIL-TYPE-THREE	004		A	00	00
22	MATRIX-TYPE-ONE	004		A	09	14
23	MATRIX-ONE-PROPORTION	002	02	N	00	00
24	MATRIX-TYPE-TWO	004		N	00	00
25	MATRIX-TWO-PROPORTICN	002	02	N	00	00
26	CEMENT-TYPE-ONE	004		A	14	21
27	CEMENT-CNE-PROPCRTION	002	02	N	01	02
28	CEMENT-TYPE-TWO	004		A	02	03
29	CEMENT-TWO-PROPORTICN	002	02	N	00	00
30	SORTING	004		A	08	12
31	ROUNDING	004		A	09	14
32	POROSITY-TYPE	004		A	12	18
33	POROSITY-PERCENT	002	00	N	09	14
34	PERMEABILITY	004	00	N	00	00
35	LITHOLOGIC-DATA-SOURCE	025		X	37	56
36	LITHOLOGIC-DATA-LOCN-LAT	004	05	N	37	56
37	LITHOLOGIC-CATA-LOCN-LONG	005	05	N	37	56
38	LITHOLOGIC-DATA-LOCN-LSD	002	00	N	37	56
39	LITHOLOGIC-DATA-LOCN-SEC	002	00	N	37	56
40	LITHOLOGIC-DATA-LOCN-TWP	003	00	N	37	56
41	LITHOLOGIC-DATA-LCCN-RGE	002	00	N	37	56
42	LITHOLOGIC-DATA-LOCN-MER	001	00	N	37	56
43	LITHOLOGIC-CATA-LCCN-PREC	001	00	N	00	00
44	LITHOLOGIC-DATA-IN-POOL	003		A	03	05

% CALCULATED FOR 148 POOLS WITH RECORDED LITHOLOGIES
9 - % OF DATA POSSIBLE WITH 9 RECORDS PER POOL
6 - % OF DATA POSSIBLE WITH 6 RECORDS PER POOL

	FIELD WIDTH	DEC	DATA TYPE	% OF DATA COLL.
*0501 GEOMETRIC CATA				
01 MAJOR-AXIS-LENGTH	004	02	N	054
02 MAJOR-AXIS-STRIKE	003	00	N	050
03 MAJOR-AXIS-SECTION-SHAPE	004		A	050
04 MINOR-AXIS-LENGTH	004	02	N	054
05 MINOR-AXIS-SECTION-SHAPE	004		A	050
06 AXIAL-INTERSECTION-DISTANCE	004	02	N	048
07 POOL-PLAN-AREA	005	03	N	096
08 MAX-RESERVOIR-THICKNESS	005	01	N	010
09 MAX-OIL-ZONE-THICKNESS	005	01	N	048
10 AVG-OIL-ZONE-THICKNESS	005	01	N	096
11 MAX-GAS-ZONE-THICKNESS	005	01	N	050
12 AVG-GAS-ZONE-THICKNESS	005	01	N	098
13 DEPTH-TO-PAY-AT-AX-INTRSECT	005	00	N	000
14 PAY-ZONE-TOP-ELEVATION	005	00	N	098
15 REGIONAL-DIP	005	01	N	088
16 REGIONAL-DIP-DIRECTION	003	00	N	088
17 FOLDING-TYPE-ONE	004		A	026
18 FOLD-AXIS-ONE-STRIKE	003	00	N	024
19 FOLD-AXIS-ONE-PLUNGE-DIR	003	00	N	016
20 FOLE-AXIS-ONE-PLUNGS	002	00	N	000
21 FOLDING-TYPE-TWO	004		A	004
22 FOLD-AXIS-TWO-STRIKE	003	00	N	004
23 FOLD-AXIS-TWO-PLUNGE-DIR	003	00	N	004
24 FOLD-AXIS-TWO-PLUNGE	002	00	N	000
25 FAULT-TYPE	004		A	002
26 FAULT-PLANE-STRIKE	003	00	N	002
27 FAULT-PLANE-DIP-DIRECTION	003	00	N	000
28 FAULT-PLANE-DIP	002	00	N	000
29 POOL-TREND-ONE	003	00	N	050
30 POCL-TREND-TWO	003	00	N	024

	FIELD WIDTH	DEC	DATA TYPE	% OF DATA COLL.
*0601 TECHNICAL DATA				
01 RESERVOIR-POROSITY-FRACTION	003	02	N	100
02 WATER-SATURATION-FRACTION	002	02	N	100
03 WATER-SALINITY-PPM	006	00	N	000
04 BCF-GAS-IN-PLACE	007	02	N	100
05 MMBBLS-OIL-IN-PLACE	008	03	N	100
06 API-GRAVITY	002	00	N	096
07 INITIAL-PRESSURE	004	00	N	098
08 TOTAL-PRODUCING-OIL-WELLS	004	00	N	058
09 TOTAL-PRODUCING-GAS-WELLS	004	00	N	058
10 WELL-SPACING-ACRES	004	00	N	048
11 TRAP-TYPE	004		A	056
12 OTHER-PRODUCTS-ONE	020		X	000
13 OTHER-PRODUCTS-TWO	020		X	000

APPENDIX II

PROPOSED STANDARD DATA SPECIFICATIONS
OIL AND GAS POOLS FILE

	FIELD WIDTH	DEC	DATA TYPE
*0101 IDENTIFICATION AND LOCATION			
INSTITUTION	04		A
REFERENCE-NUMBER	10		N
PROVINCE	04		A
AUTHORITY	20		X
FIELD-NAME	20		X
FIELD-CODE	03		N
POOL-NAME	20		X
FORMATION-CODE	03		X
POOL-CODE	03		X
AXIAL-LOCATION-LAT	# 02	05	N
AXIAL-LOCATION-LONG	# 03	05	N
# AXIAL-LOCATION-UTM-NORTHING	09		N
# AXIAL-LOCATION-UTM-EASTING	08		N
# AXIAL-LOCATION-UTM-ZONE	03		N
AXIAL-LOCATION-LSD	02		N
AXIAL-LOCATION-SEC	02		N
AXIAL-LOCATION-TWP	03		N
AXIAL-LOCATION-RGE	02		N
AXIAL-LOCATION-MER	01		N
AXIAL-LOCATION-PRECISION	01		N
POOL-TYPE	04		A
REGIONAL-TECTONIC-ELEMENT	20		X
RELATED-TO-UNCONFORMITY	04		A
REFERENCE-TEXT	25		X

SUGGESTED CHANGES TO DATA SPECIFICATIONS

*0203 STRATIGRAPHIC DATA
AS IN APPENDIX I

*0301 UNCONFORMITY DATA
AS IN APPENDIX I

	FIELD WIDTH	DEC	DATA TYPE
# *0406 LITHOLOGY			
ROCK-TYPE	04		A
PROPORTION-OF-LITHOLOGY	# 00	02	N
RELATION-TO-POOL	01		A
STRAT-UNIT-GROUP	08		X
STRAT-UNIT-FORMATION	08		X
STRAT-UNIT-MEMBER	08		X
STRAT-UNIT-INFORMAL	08		X
COLOUR	04		A
CRYSTALLINITY	04		A
UPPER-SIZE-LIMIT	04		A
MEDIAN-SIZE	04		A
LOWER-SIZE-LIMIT	04		A
CLAST-COMPOSITION-ONE	04		A
CLAST-ONE-PROPORTION	# 00	02	N
CLAST-COMPOSITION-TWO	04		A
# ACCESSORY-MIN	04		A
# FOSSIL-TYPE	04		A
# MATRIX-TYPE	04		A
# MATRIX-PROPORTION	# 0	02	N
# CEMENT-TYPE	04		A
# CEMENT-PROPORTION	# 00	02	N
SORTING	04		A
POROSITY-TYPE	04		A
POROSITY-PERCENT	02		N
LITHOLOGIC-DATA-SOURCE	25		X
LITHOLOGIC-DATA-LOCN-LAT	02	05	N
LITHOLOGIC-DATA-LOCN-LONG	03	05	N
# LITHOLOGIC-DATA-LOCN-DLS	11		X
LITHOLOGIC-DATA-IN-POOL	03		A

SUGGESTED CHANGES TO DATA SPECIFICATIONS

*0501 GEOMETRIC DATA
AS IN APPENDIX I

*0601 TECHNICAL DATA
AS IN APPENDIX I

APPENDIX III

RETRIEVAL REQUEST EXAMPLE

```
IF ((360 GT FORMATION-CODE)
  AND (309 LT FORMATION-CODE)
  AND (1.0 LT POOL-PLAN-AREA))
PRINT REFERENCE-NUMBER
AXIAL-LOCATION-TWP AXIAL-LOCATION-RGE
  AXIAL-LOCATION-MER POOL-TYPE
  REGIONAL-TECTONIC-ELEMENT
RELATED-TO-UNCONFORMITY POOL-PLAN-AREA
PAY-ZONE-TOP-ELEVATION
FOLDING-TYPE-ONE REGIONAL-DIP
REGIONAL-DIP-DIRECTION
MAJOR-AXIS-STRIKE
POOL-TREND-ONE POOL-TREND-TWO
IN FORMAT S/1/ N/10/ S/2/ Z/3/ Z/3/
Z/2/ S/5/ A/4/ S/5/ X/20/ S/2/ A/3/
    Z/8/.N/3/ S/3/ N/5/ S/3/ A/4/ S/3/
    Z/5/.N/1/ Z/5/ S/3/ Z/3/ Z/5/ Z/5/
STOP
```

IF THE FORMATION CODE IS BETWEEN 309

AND 360, I.E. LOWER MANNVILLE, AND IF

THE POOL PLAN AREA IS GREATER THAN 1

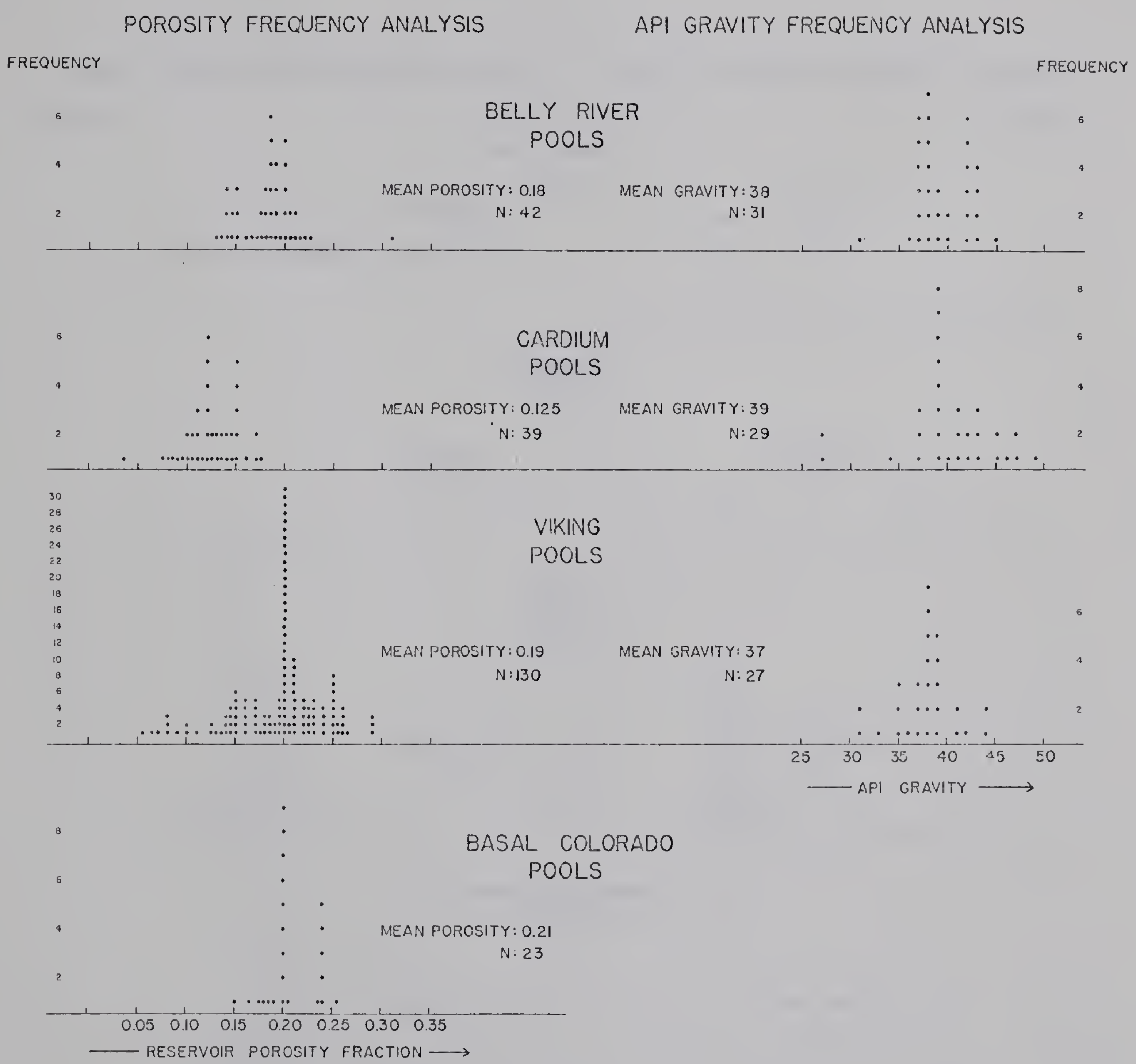
SQUARE MILE

THEN PRINT THE REQUESTED DATA IN THE

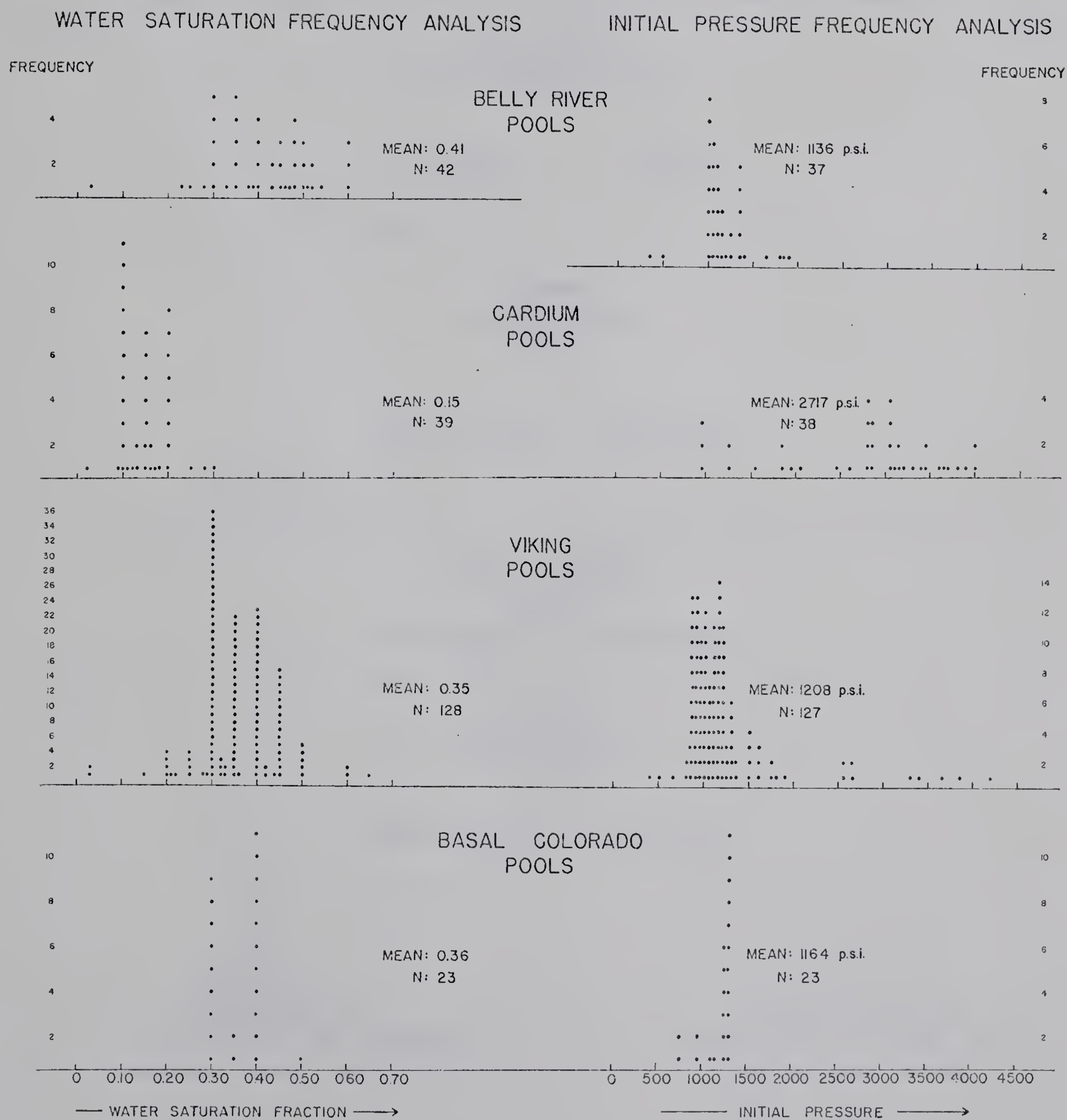
FORMAT SPECIFIED

(N.B. Z FORMAT IS ZERO SUPPRESSION)

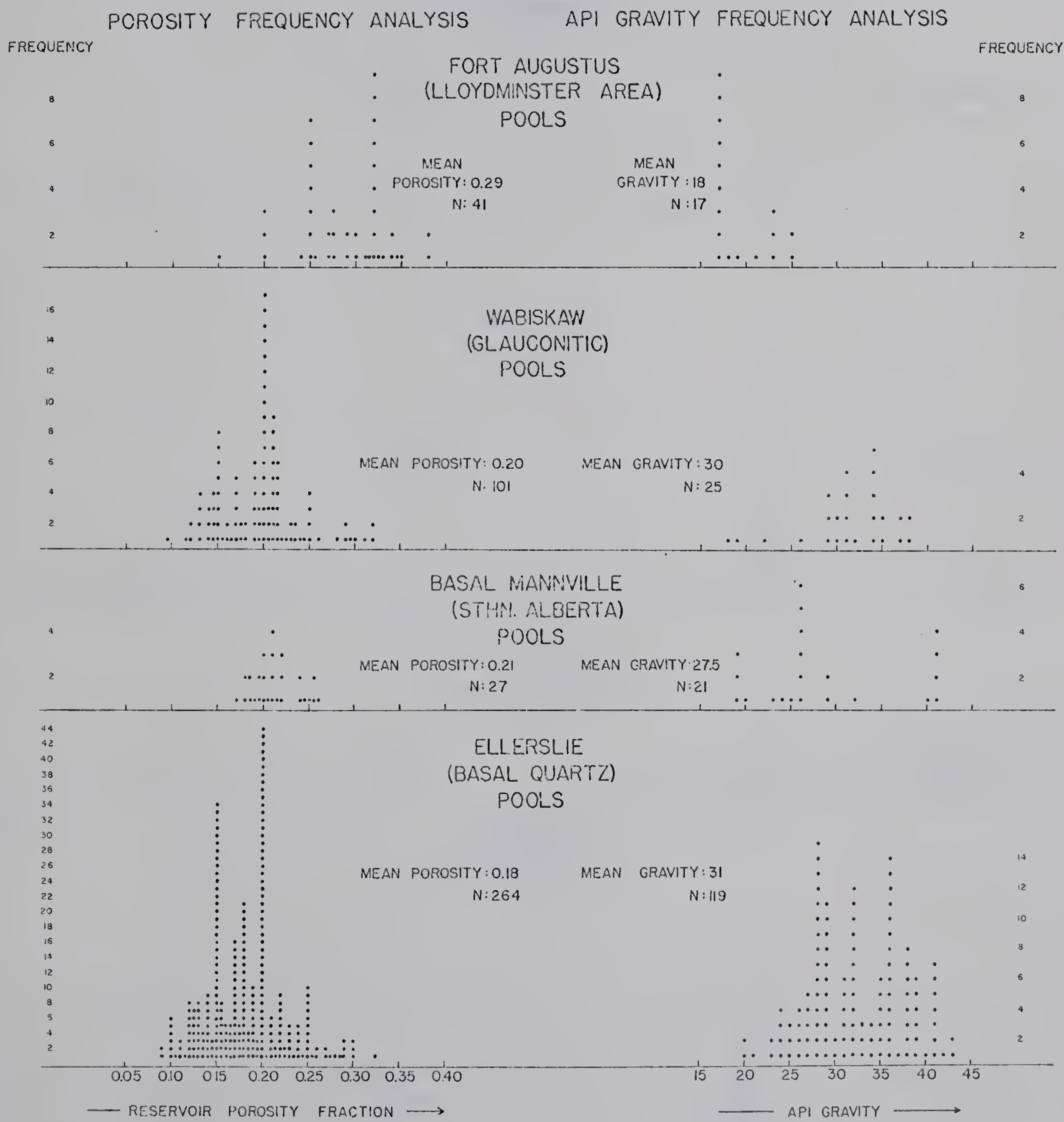
APPENDIX IV a



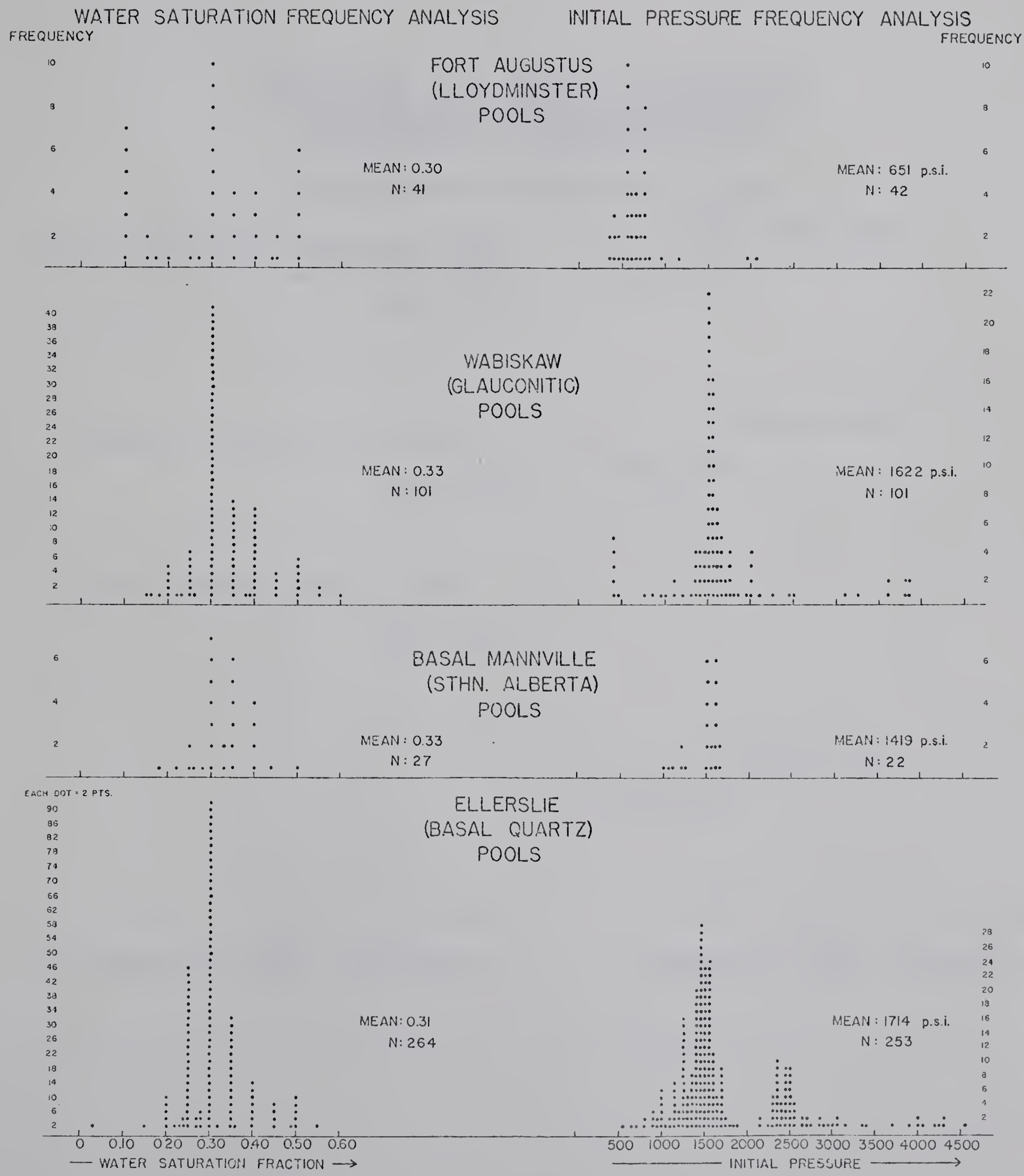
APPENDIX IV b



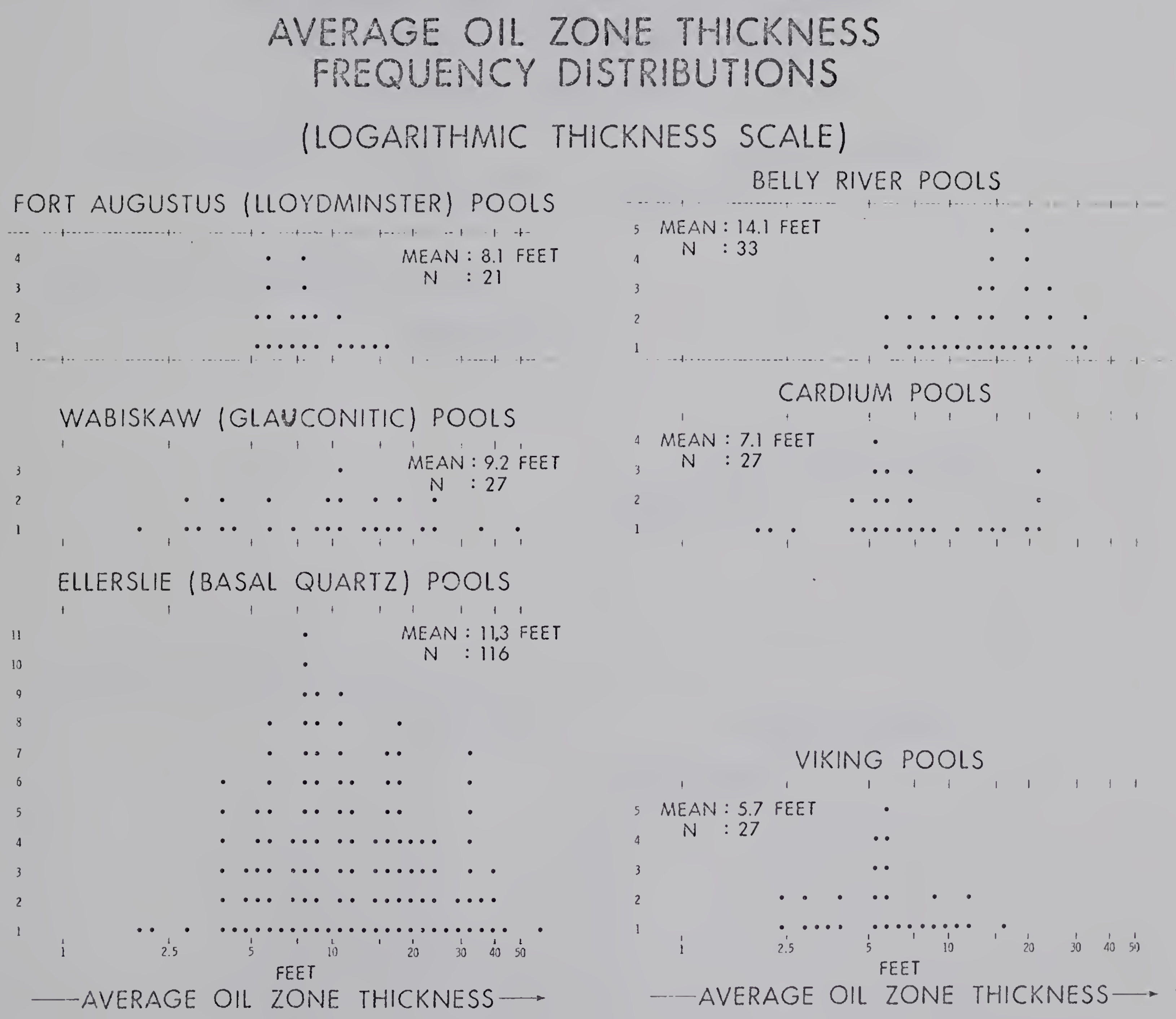
APPENDIX IV c



APPENDIX IV d



APPENDIX IV e



APPENDIX IV f

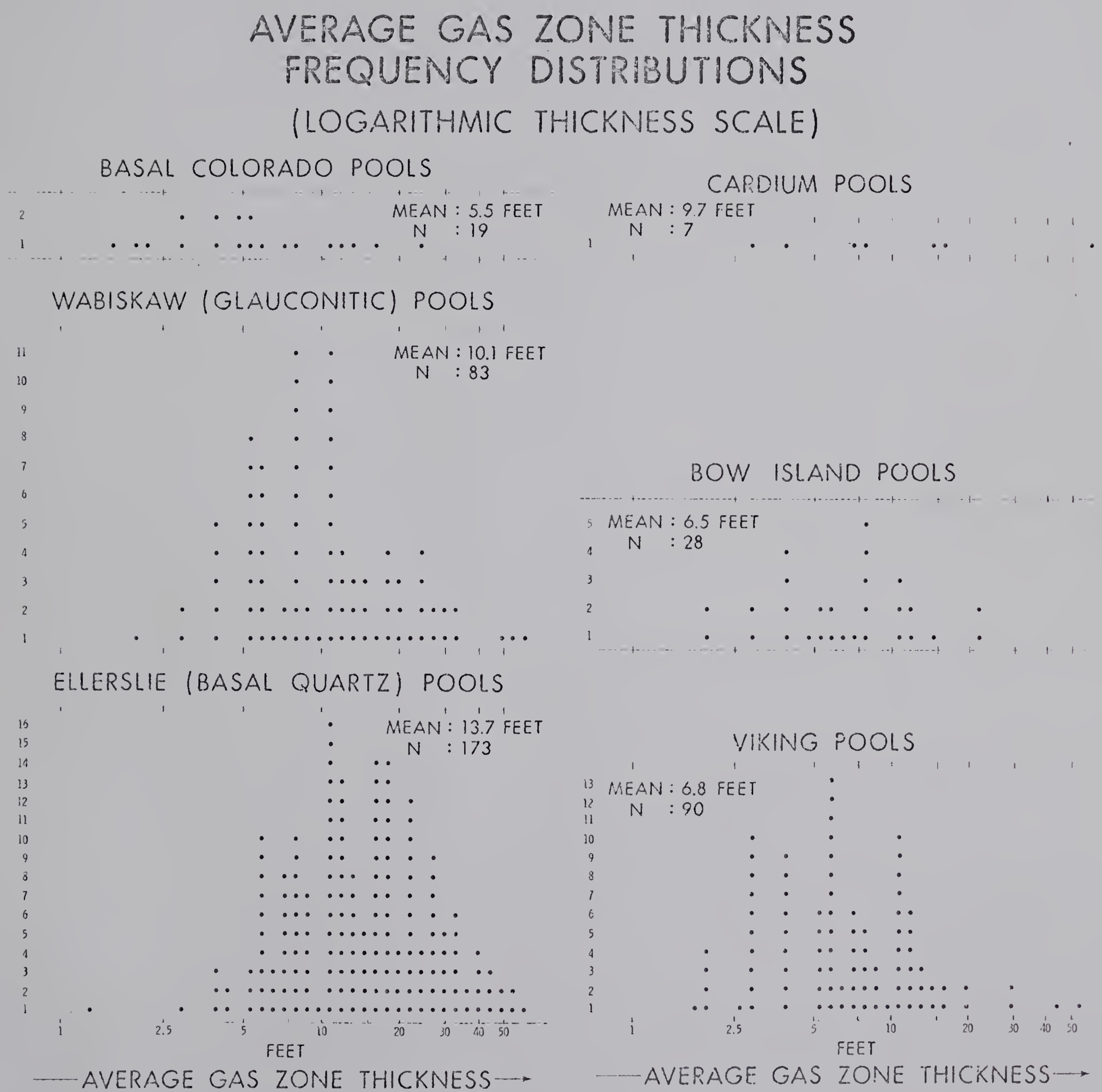


FIGURE 1. SOURCE DOCUMENT

CRETACEOUS AND JURASSI

CODE /INSTITUTION /REFERENCE-NUMBER /PROVINCE /AUTHORITY

*0101/ / / /

FIELD-NAME /FIELD-CODE /POOL-NAME

/ /

AXIAL-LOCATION-LAT /AXIAL-LOCATION-LONG /AXIAL-LOCATION-UTM-NORTHING

/ /

AXIAL-LOCATION-LSD /AXIAL-LOCATION-SEC /AXIAL-LOCATION-TWP /AXIAL-LOC

/ / /

POOL-TYPE /REGIONAL-TECTONIC-ELEMENT /RELATED-TO-UNCONF

/ /

CODE /STRAT-POSITION-OF-UNIT /STRAT-UNIT-GP-NAME /STRAT-UNIT-GP-MOD /

*0201/ / / /

STRAT-UNIT-FM-AGE /STRAT-UNIT-MBR-NAME /STRAT-UNIT-MBR-MOD /STRAT-UNI

/ / /

STRAT-UNIT-INFORMAL-MOD /STRAT-UNIT-INFORMAL-AGE /GENERAL-DEPOS-ENVIR

/ /

CODE /STRAT-POSITION-OF-UNIT /STRAT-UNIT-GP-NAME /STRAT-UNIT-GP-MOD /

*0202/ / / /

STRAT-UNIT-FM-AGE /STRAT-UNIT-MBR-NAME /STRAT-UNIT-MBR-MOD /STRAT-UNI

/ / /

STRAT-UNIT-INFORMAL-MOD /STRAT-UNIT-INFORMAL-AGE /GENERAL-DEPOS-ENVIR

/ /

CODE /STRAT-POSITION-OF-UNIT /STRAT-UNIT-GP-NAME /STRAT-UNIT-GP-MOD /

*0203/ / / /

STRAT-UNIT-FM-AGE /STRAT-UNIT-MBR-NAME /STRAT-UNIT-MBR-MOD /STRAT-UNI

/ / /

COPY 5 PAGE 1

C OIL AND GAS POOLS

/

/

/FORMATION-CODE /POOL-CODE /

/ / /

/AXIAL-LOCATION-UTM-EASTING /AXIAL-LOCATION-UTM-ZONE /

/ / /

CATION-RGE /AXIAL-LOCATION-MER /AXIAL-LOCATION-PRECISION /

/ / /

FORMITY /REFERENCE-TEXT /

/ /

/STRAT-UNIT-GP-AGE /STRAT-UNIT-FM-NAME /STRAT-UNIT-FM-MOD /

/ / / /

IT-MBR-AGE /STRAT-UNIT-INFORMAL-NAME /

/ /

RONMENT /DETAILED-DEPOS-ENVIRONMENT /

/ /

/STRAT-UNIT-GP-AGE /STRAT-UNIT-FM-NAME /STRAT-UNIT-FM-MOD /

/ / / /

IT-MBR-AGE /STRAT-UNIT-INFORMAL-NAME /

/ /

RONMENT /DETAILED-DEPOS-ENVIRONMENT /

/ /

/STRAT-UNIT-GP-AGE /STRAT-UNIT-FM-NAME /STRAT-UNIT-FM-MOD /

/ / / /

IT-MBR-AGE /STRAT-UNIT-INFORMAL-NAME /

/ /

STRAT-UNIT-INFORMAL-MOD /STRAT-UNIT-INFORMAL-AGE /GENERAL-DEPOS-ENVIR

/ /

CODE /UNCCNFORMITY-TYPE /POOL-RELATION-TO-UNCONF /RELATED-UNCONF-RELI

*0301/ / /

UNIT-ABOVE-UNCONF-GP-NAME /UNIT-AEOVE-UNCONF-GP-MOD /UNIT-AEOVE-UNCON

/ /

UNIT-ABOVE-UNCONF-FM-MOD /UNIT-ABOVE-UNCONF-FM-AGE /UNIT-ABOVE-UNCONF

/ /

UNIT-ABOVE-UNCONF-MER-ACE /UNIT-AEOVE-UNCONF-INF-NAME /UNIT-ABOVE-UNC

/ /

UNIT-BELOW-UNCONF-GP-NAME /UNIT-BELOW-UNCONF-GP-MOD /UNIT-BELOW-UNCON

/ /

UNIT-BELOW-UNCONF-FM-MOC /UNIT-BELOW-UNCONF-FM-AGE /UNIT-BELOW-UNCONF

/ /

UNIT-BELOW-UNCONF-MBR-AGE /UNIT-BELOW-UNCCNF-INF-NAME /UNIT-BELOW-UNC

/ /

CODE /ROCK-TYPE /PFOPCRTION-OF-LITHOLOGY /RELATICN-TO-POOL /STRATIGRA

*0401/ / / /

STRATIGRAPHIC-UNIT-MEMBER /STRATIGRAPHIC-UNIT-INFORMAL /COLOR /CRYS

/ / /

CLAST-COMFOSITION-ONE /CLAST-ONE-PROPORTION /CLAST-COMPOSITION-TWO /A

/ / /

CEMENT-TYPE /CEMENT-PROPORTION /SCRTING /POROSITY-TYPE /POROSITY-PERC

/ / / /

LITHOLOGIC-DATA-LCCN-LAT /LITHOLOGIC-DATA-LOCN-LONG /LITHOLOGIC-DATA-

/ /

COPY 5 PAGE 2

C OIL AND GAS POOLS

ONMENT /DETAILED-DEPOS-ENVIRONMENT /

/ /

EF-FEATURE /VERTICAL-DISTANCE-FROM-UNCONF /

/ /

F-GP-AGE /UNIT-ABOVE-UNCONF-FM-NAME /

/ /

-MBR-NAME /UNIT-ABOVE-UNCONF-MBR-MOD /

/ /

ONF-INF-MOD /UNIT-ABOVE-UNCONF-INF-AGE /

/ /

F-GP-AGE /UNIT-BELOW-UNCONF-FM-NAME /

/ /

-MBR-NAME /UNIT-BELOW-UNCONF-MBR-MOD /

/ /

ONF-INF-MOD /UNIT-BELOW-UNCONF-INF-AGE /

/ /

PHIC-UNIT-GROUP /STRATIGRAPHIC-UNIT-FM /

/ /

STALLINITY /UPPER-SIZE-LIMIT /MEDIAN-SIZE /LOWER-SIZE-LIMIT /

/ / / /

CCESSORY-MIN /FOSSIL-TYPE /MATRIX-TYPE /MATRIX-PROPORTION /

/ / / /

ENT /LITHOLOGIC-DATA-SOURCE /

/ /

-LOCN-DLS /LITHOLOGIC-DATA-IN-POOL /

/ /

CODE /ROCK-TYPE /PROPORTION-OF-LITHOLOGY /RELATION-TO-POOL /STRATIG

*0402/ / / /

STRATIGRAPHIC-UNIT-MEMBER /STRATIGRAPHIC-UNIT-INFORMAL /COLOR /CR

/ / /

CLAST-COMPOSITION-ONE /CLAST-ONE-PROPORTION /CLAST-COMPOSITION-TWO

/ /

CEMENT-TYPE /CEMENT-PROPORTION /SORTING /POROSITY-TYPE /POROSITY-PE

/ / / / /

LITHOLOGIC-DATA-LOCN-LAT /LITHOLOGIC-DATA-LOCN-LONG /LITHOLOGIC-DA

/ /

CODE /ROCK-TYPE /PROPORTION-OF-LITHOLOGY /RELATION-TO-POOL /STRATI

*0403/ / / /

STRATIGRAPHIC-UNIT-MEMBER /STRATIGRAPHIC-UNIT-INFORMAL /COLOR /C

/ / /

CLAST-COMPOSITION-ONE /CLAST-ONE-PROPORTION /CLAST-COMPOSITION-TW

/ /

CEMENT-TYPE /CEMENT-PROPORTION /SORTING /POROSITY-TYPE /POROSITY-

/ / / / /

LITHOLOGIC-DATA-LOCN-LAT /LITHOLOGIC-DATA-LOCN-LONG /LITHOLOGIC-D

/ /

CODE /ROCK-TYPE /PROPORTION-OF-LITHOLOGY /RELATION-TO-POOL /STRAT

*0404/ / / /

STRATIGRAPHIC-UNIT-MEMBER /STRATIGRAPHIC-UNIT-INFORMAL /COLOR /

/ / /

CLAST-COMPOSITION-ONE /CLAST-ONE-PROPORTION /CLAST-COMPOSITION-T

/ /

IC OIL AND GAS POOLS

APHIC-UNIT-GROUP /STRATIGRAPHIC-UNIT-FM /

/ /

/STALLINITY /UPPER-SIZE-LIMIT /MEDIAN-SIZE /LOWER-SIZE-LIMIT /

/ / / /

/ACCESSORY-MIN /FOSSIL-TYPE /MATRIX-TYPE /MATRIX-PROPORTION /

/ / / / /

RCENT /LITHOLOGIC-DATA-SOURCE /

/ /

A-LOCN-DLS /LITHOLOGIC-DATA-IN-POOL /

/ /

GRAPHIC-UNIT-GROUP /STRATIGRAPHIC-UNIT-FM /

/ /

RYSTALLINITY /UPPER-SIZE-LIMIT /MEDIAN-SIZE /LOWER-SIZE-LIMIT /

/ / / /

/ACCESSORY-MIN /FOSSIL-TYPE /MATRIX-TYPE /MATRIX-PROPORTION /

/ / / / /

PERCENT /LITHOLOGIC-DATA-SOURCE /

/ /

ATA-LOCN-DLS /LITHOLOGIC-DATA-IN-POOL /

/ /

IGRAPHIC-UNIT-GROUP /STRATIGRAPHIC-UNIT-FM /

/ /

CRYSTALLINITY /UPPER-SIZE-LIMIT /MEDIAN-SIZE /LOWER-SIZE-LIMIT /

/ / / /

O /ACCESSORY-MIN /FOSSIL-TYPE /MATRIX-TYPE /MATRIX-PROPORTION /

/ / / / /

CEMENT-TYPE /CEMENT-PROPORTION /SORTING /POROSITY-TYPE /POROSITY-PERCE

/ / / /

LITHOLOGIC-DATA-LOCN-LAT /LITHOLOGIC-DATA-LOCN-LONG /LITHOLOGIC-DATA-L

/ /

CODE /ROCK-TYPE /PROPORTION-OF-LITHOLOGY /RELATION-TO-POOL /STRATIGRAP

*0405/ / / /

STRATIGRAPHIC-UNIT-MEMBER /STRATIGRAPHIC-UNIT-INFORMAL /COLOR /CRYST

/ / /

CLAST-COMPOSITION-ONE /CLAST-ONE-PROPORTION /CLAST-COMPOSITION-TWO /A

/ / /

CEMENT-TYPE /CEMENT-PROPORTION /SORTING /POROSITY-TYPE /POROSITY-PERC

/ / / /

LITHOLOGIC-DATA-LOCN-LAT /LITHOLOGIC-DATA-LOCN-LONG /LITHOLOGIC-DATA-

/ /

CODE /ROCK-TYPE /PROPORTION-OF-LITHOLOGY /RELATION-TO-POOL /STRATIGRA

*0406/ / / /

STRATIGRAPHIC-UNIT-MEMBER /STRATIGRAPHIC-UNIT-INFORMAL /COLOR /CRYS

/ / /

CLAST-COMPOSITION-ONE /CLAST-ONE-PROPORTION /CLAST-COMPOSITION-TWO /A

/ / /

CEMENT-TYPE /CEMENT-PROPORTION /SORTING /POROSITY-TYPE /POROSITY-PER

/ / / /

LITHOLOGIC-DATA-LOCN-LAT /LITHOLOGIC-DATA-LOCN-LONG /LITHOLOGIC-DATA-

/ /

CODE /MAJOR-AXIS-LENGTH /MAJOR-AXIS-STRIKE /MAJOR-AXIS-SECTION-SHAPE

*0501/ / /

OIL AND GAS POOLS

NT /LITHOLOGIC-DATA-SOURCE /

/ /

LOCN-DLS /LITHOLOGIC-DATA-IN-POOL /

/ /

PHIC-UNIT-GROUP /STRATIGRAPHIC-UNIT-FM /

/ /

TALLINITY /UPPER-SIZE-LIMIT /MEDIAN-SIZE /LOWER-SIZE-LIMIT /

/ / / /

CCESSORY-MIN /FOSSIL-TYPE /MATRIX-TYPE /MATRIX-PROPORTION /

/ / / /

ENT /LITHOLOGIC-DATA-SOURCE /

/ /

LOCN-DLS /LITHOLOGIC-DATA-IN-POOL /

/ /

PHIC-UNIT-GROUP /STRATIGRAPHIC-UNIT-FM /

/ /

TALLINITY /UPPER-SIZE-LIMIT /MEDIAN-SIZE /LOWER-SIZE-LIMIT /

/ / / /

CCESSORY-MIN /FOSSIL-TYPE /MATRIX-TYPE /MATRIX-PROPORTION /

/ / / /

CENT /LITHOLOGIC-DATA-SOURCE /

/ /

-LOCN-DLS /LITHOLOGIC-DATA-IN-POOL /

/ /

/MINOR-AXIS-LENGTH /MINOR-AXIS-SECTION-SHAPE /

/ / /

AXIAL-INTERSECTION-DISTANCE /POOL-PLAN-AREA /MAX-RESERVOIR-THICKNESS

/ /

MAX-GAS-ZONE-THICKNESS /AVG-GAS-ZONE-THICKNESS /DEPTH-TO-PAY-AT-AX-IN

/ /

REGIONAL-DIP-DIRECTION /FOLDING-TYPE-ONE /FOLD-AXIS-ONE-STRIKE /FOLD-

/ / /

FOLD-AXIS-TWO-STRIKE /FOLD-AXIS-TWO-PLUNGE-DIR /FOLD-AXIS-TWO-PLUNGE

/ /

FAULT-PLANE-DIP /POOL-TREND-ONE /POOL-TREND-TWO /

/ / /

CODE /RESERVOIR-POROSITY-FRACTION /WATER-SATURATION-FRACTION /WATER-S

*0601/ / /

API-GRAVITY /INITIAL-PRESSURE /TOTAL-PRODUCING-OIL-WELLS /TOTAL-PRODU

/ / /

OTHER-PRODUCTS-ONE /OTHER-PRODUCTS-TWO

/

C OIL AND GAS POOLS

/MAX-OIL-ZONE-THICKNESS /AVG-OIL-ZONE-THICKNESS /

/ / /

TRSECT /PAY-ZONE-TOP-ELEVATION /REGIONAL-DIP /

/ / /

AXIS-ONE-PLUNGE-DIR /FOLD-AXIS-ONE-PLUNGE /FOLDING-TYPE-TWO /

/ / /

/FAULT-TYPE /FAULT-PLANE-STRIKE /FAULT-PLANE-DIP-DIRECTION /

/ / / /

ALINITY-PPM /BCF-GAS-IN-PLACE /MMBBLS-OIL-IN-PLACE /

/ / /

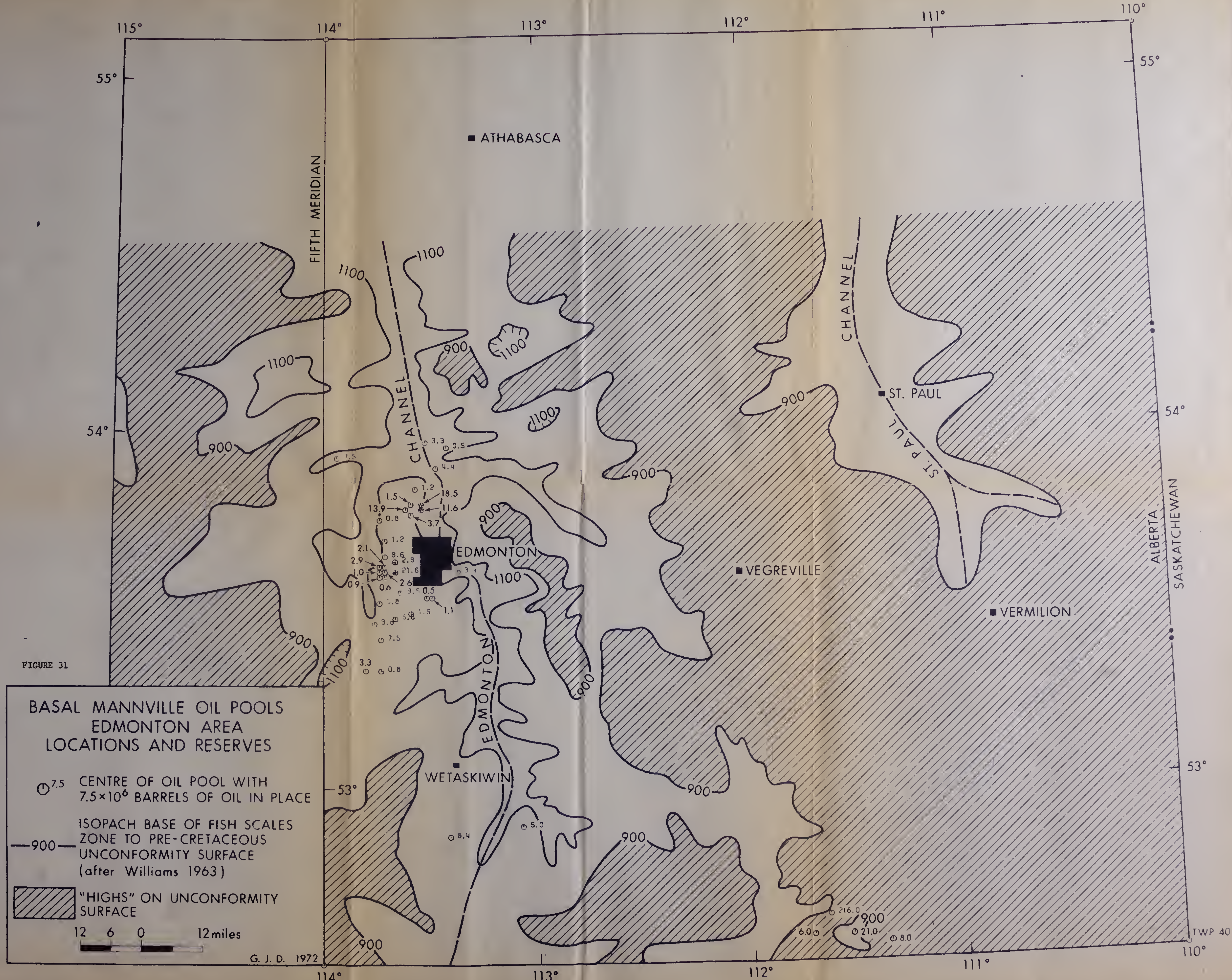
JCING-GAS-WELLS /WELL-SPACING-ACRES /TRAP-TYPE /

/ / /

/

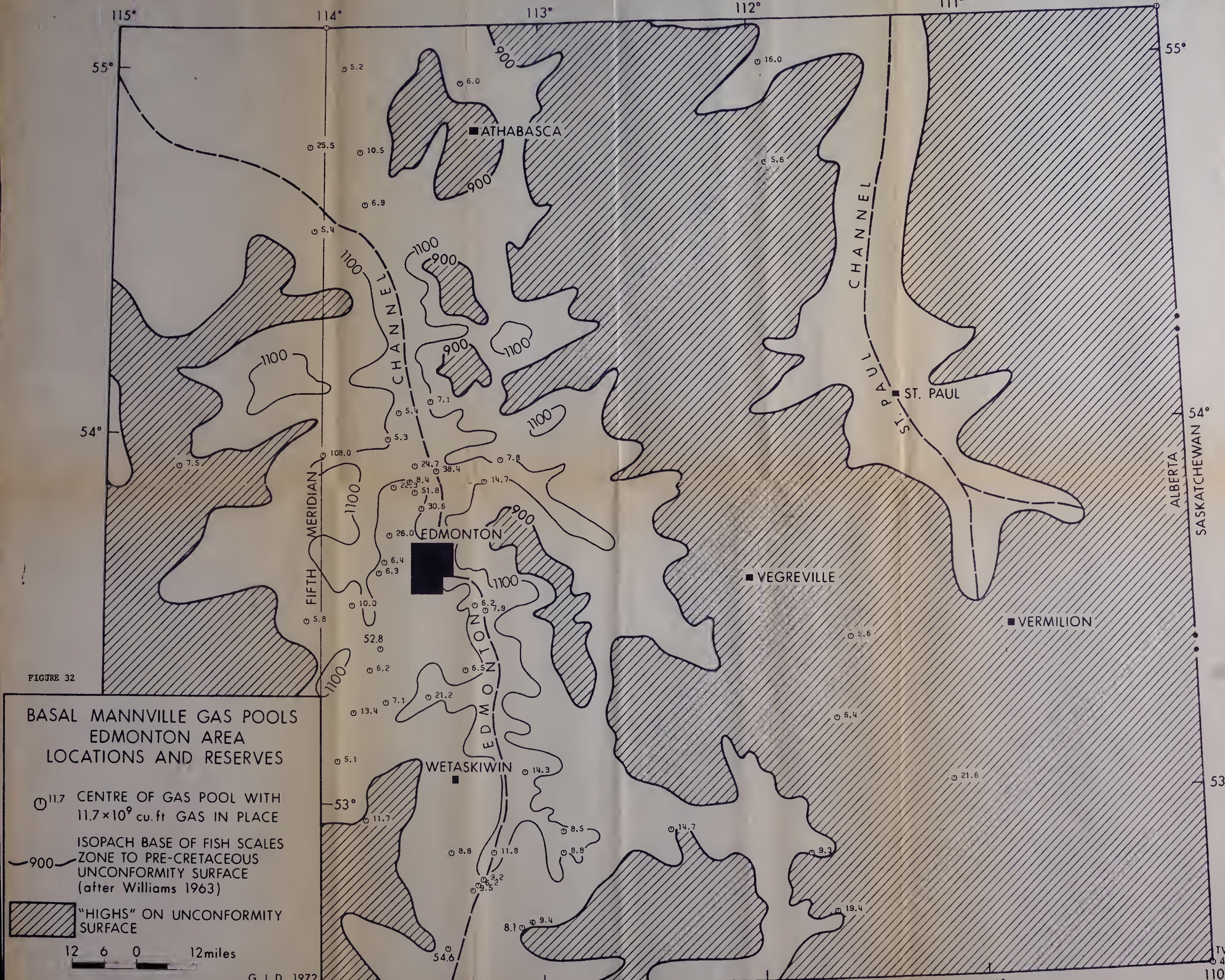
/

FIGURE 31



BASAL MANNVILLE OIL POOLS
EDMONTON AREA
LOCATIONS AND RESERVES
7.5 CENTRE OF OIL POOL WITH 7.5×10^6 BARRELS OF OIL IN PLACE
—900— ISOPACH BASE OF FISH SCALES ZONE TO PRE-CRETACEOUS UNCONFORMITY SURFACE (after Williams 1963)
"HIGHS" ON UNCONFORMITY SURFACE
12 6 0 12 miles
G. J. D. 1972
115°
114°
113°
112°
111°
110°
55°
54°
53°
TWP 40
FIFTH MERIDIAN
ATHABASCA
ST. PAUL
VEGREVILLE
VERMILION
EDMONTON
WETASKIWIN
ALBERTA
SASKATCHEWAN
EDMONTON CHANNEL
ST. PAUL CHANNEL
1100
900

FIGURE 32


BASAL MANNVILLE GAS POOLS
EDMONTON AREA
LOCATIONS AND RESERVES
11.7 CENTRE OF GAS POOL WITH 11.7×10⁹ cu.ft GAS IN PLACE
900 ISOPACH BASE OF FISH SCALES ZONE TO PRE-CRETACEOUS UNCONFORMITY SURFACE (after Williams 1963)
"HIGHS" ON UNCONFORMITY SURFACE
12 6 0 12miles
G. J. D. 1972
ATHABASCA
EDMONTON
VEGREVILLE
ST. PAUL
VERMILION
WETASKIWIN
CHANNEL
ST. PAUL CHANNEL
EDMONTON
FIFTH MERIDIAN
ALBERTA
SASKATCHEWAN
TWP 40
115°
114°
113°
112°
111°
110°
55°
54°
53°